IS 9018 (1978): General requirements and tests for quartz crystal oscillators [LITD 12: Transmitting Equipment for Radio Communication]

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(Reaffirmed 2000)

Indian Standard

GENERAL REQUIREMENTS AND TESTS FOR QUARTZ CRYSTAL OSCILLATORS

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Indian Standard

GENERAL REQUIREMENTS AND TESTS FOR QUARTZ CRYSTAL OSCILLATORS

Piezoelectric Devices for Frequency Control and Selection Sectional Committee, LTDC 12

Indian Standard

GENERAL REQUIREMENTS AND TESTS FOR QUARTZ CRYSTAL OSCILLATORS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 23 November 1978, after the draft finalized by the Piezoelectric Devices for Frequency Control and Selection Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This standard relates to quartz crystal oscillators intended for use in electronic applications.

0.3 The object of this standard is to establish uniform conditions for assessing the mechanical, electrical and climatic properties of quartz crystal oscillators; to describe test methods; to recommend classification into groups according to their ability to withstand extremes of temperature, humidity, pressure, or mechanical stress; and to provide guidance in the use and maintenance of quartz crystal oscillators.

0.4 The applicability and specific requirements for each test will be given in the relevant specification for a specific oscillator type. In case of conflict between the requirements of this standard on the one hand, and the relevant specification on the other hand, the relevant specification will be valid.

0.5 This standard requires reference to IS : 589 - 1961* so far as the details of the climatic and mechanical testing procedures are concerned, only the relevant degrees and severities and the performance requirements have been specified in this standard.

0.6 While preparing this standard, assistance has been derived from the following publications issued by the International Electrotechnical Commission:

IEC Doc : 49 (Sectt) 83 Second Draft — Quartz crystal controlled oscillators

IEC Doc : 49 (C.O.) 107 Draft Quartz crystal controlled oscillators

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2 - 1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

†Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard specifies general requirements and methods of tests, common to all types of quartz crystal oscillators.

2. TERMINOLOGY

2.1 For the purpose of this standard, the following definitions in addition to those covered by IS : 1885 (Part XLIV)-1978* shall apply.

2.1.1 ***Type Tests*** — Tests carried out to prove conformity with the requirements of the relevant specification. These are intended to check the general qualities and design of a given type of quartz crystal oscillators.

2.1.2 ***Acceptance Tests*** -Tests carried out on samples selected from a lot for purposes of acceptance of the lot.

2.1.2.1 ***Lot*** — All quartz crystal oscillators of the same type, grade, category and rating manufactured by the same factory during the same period, using the same process and materials.

2.1.3 ***Routine Tests*** -Tests carried out on each and every quartz crystal oscillators to check the requirements which are likely to vary during production.

3. CLASSIFICATION OF CRYSTAL OSCILLATORS

3.1 The classification of crystal oscillators is as given below:

Class 1 — Crystal oscillators (XO).

Class 2 — Voltage controlled crystal oscillators (VCXO).

Class 3 — Temperature compensated crystal oscillators (TCXO).

Class 4 — Oven temperature controlled crystal oscillators (OCXO).

Class 5 — Temperature compensated voltage controlled crystal oscillators (TCVCXO).

4. MARKING

4.1 Each quartz crystal oscillator shall have the following information legibly and indelibly marked upon it:

a) Nominal frequency,

b) Supply voltage and polarity,

c) Mark of origin,

d) Date of manufacture,

*Electrotechnical vocabulary : Part XLIV Piezoelectric devices.

e) Designation and pin connections,
f) Identification code, and
g) Any other information required.

NOTE 1 - The frequency shall be specified to the final hertz and shall consist of 7 digits or less for frequencies below 10 MHz, 8 digits or less for the range 10 MHz to 100 MHz and 9 digits for frequencies 100 MHz and above. However, the digits may be restricted to the last significant digit after decimal point.

Example:

123,888 889 MHz
123,888 MHz
123,88 MHz

NOTE 2 — The frequency marking shall occupy a maximum of 13 spaces as follows:

A maximum of 9 digits, a space for a decimal point, and 3 spaces for 'kHz' or 'MHz' whichever is applicable; typical crystal oscillator markings are 833.333 kHz, 45·555556 MHz and 123·888889 MHz.

NOTE 3 — The characteristics of the marking shall be not less than 1·6 mm in height unless otherwise specified.

4.1.1 The oscillators may also be marked with the IS1 Certification Mark.

NOTE - The use of the IS1 Certification Mark is governed by de provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The IS1 Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard, under a well-defined system of inspection, testing and quality control which is devised and supervised by IS1 and operated by the producer. IS1 marked products are also continuously checked by IS1 for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the IS1 Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

5. CLASSIFICATION OF TESTS

5.1 Type Tests — Unless otherwise specified, the procedure for type approval shall be in accordance with IS : 2612-1965*. The sequence of type tests and number of samples for each test shall be in accordance with Table 1. The sample shall be selected at random preferably from regular production.

5.2 Routine **Tests** — The following tests shall constitute routine tests and shall be carried out on every crystal oscillator:

a) Visual examination (external) (7),
b) Dimensions and mass (8),
c) Insulation resistance (9.1),
d) Output frequency (9.4),
e) Frequency adjustment (9.7),
f) Oscillator output voltage (9.9.1),
g) Harmonic distortion (when specified) (9.11.6), and
h) Spurious response (when specified) (9.12.1).

*Recommendation for type approval and sampling procedures for electronic components.

TABLE 1 SCHEDULE OF **TYPE TESTS**

(*Clause* 5.1)

GROUP	TEST	NUMBER OF SAMPLES	REFERENCE TO CLAUSE
(1)	(2)	(3)	(4)
0	Visual examination (external)	4	7
	Dimensions and mass		8
	Sealing (when specified)		10.2
	Voltage proof		9.2
	Insulation resistance		9.1
	*Input power (when applicable)		9.3
	†Amplitude modulation input impedance		9.10.6
	*Frequency modulation input impedance		9.11.5
	Output frequency		9.4
	Load coefficient		9.6.1
	Voltage coefficient		9.6.2
	Frequency/temperature characteristics (when specified)		9.5
	†Frequency stability with thermal transient (when specified)		9.6.3
	‡Frequency adjustment		9.7
	Retrace characteristic (when specified)		9.8
	Oscillator output impedance (when specified)		9.9.3
	Oscillator output voltage		9.9.1
	§Oscillator output power		9.9.2
	Oscillator output waveform (when specified)		9.9.4
	Re-entrant isolation		9.9.5
	Output suppression of gated oscillator		9.9.6
	Amplitude modulation index		9.10.1
	Amplitude modulation sensitivity		9.10.2

*Applicable only to oscillators with oven temperature control.
†Applicable only to oscillators with a modulated input voltage.
‡Applicable only to oscillators with a frequency adjustment.
§Applicable only to oscillators with a sine wave output signal.

(Continued)

TABLE 1 SCHEDULE OF TYPE TESTS — *Contd*

GROUP	TEST	NUMBER OF SAMPLES	REFERENCE TO CLAUSE
(1)	(2)	(3)	(4)
0	*Amplitude modulation distortion (non-linearity)		9.10.3
	*Frequency modulation distortion (non-linearity)		9.11.3
	Amplitude modulation frequency response		9.10.4
	Frequency modulation frequency response		9.11.4
	Pulse amplitude modulation		9.10.5
	Harmonic distortion (when specified)		9.11.6
	Spurious response (when specified)		9.121
	Short term frequency stability-frequency domain measurements (when specified)		9.13.1
	†Incidental FM on an AM signal		9.10.7
	Frequency modulation deviation		9.11.1
	Frequency modulation sensitivity		9.11.2
	†Stabilization time		9.6.4
	Endurance		11
	Short term frequency stability-time domain measurements (when specified)		9.13.2
	Electromagnetic interference (radiated)		9.14
	Robustness of termination		10.1
	Solderability		10.3
	Rapid change of temperature		10.4
	Bump		10.5
	Vibration		10.6
	Shock		10.7
1	Low air pressure (when specified)	2	10.9
	Climatic sequence		10.10
	Damp heat (long term exposure)		10.11
	Mould growth		10.13
2	Endurance	2	11
	Harmonic distortion		9.11.6
	Salt mist		10.12
	Acceleration, steady state		10.8
	Sealing (when specified)		10.2

NOTE — There would be no failure in critical parameters which are listed in detail specification. Only one failure is allowed in any one of the other parameters.

*Applicable only to oscillators with a sine wave output signal.

†Applicable only to oscillators with a modulated input voltage.

5.3 Acceptance Tests — The quartz crystal oscillators which have passed the routine tests shall be subjected to these tests. The acceptance tests and the failure criteria shall be as given in Table 2.

6. GENERAL CONDITIONS FOR TESTS

6.0 Information of a general nature applying to electrical measurement methods and general precautions to be observed during measurements are given in 6.1 to 6.9.

6.1 Alternative Test Methods-The measurement methods and test conditions specified in this standard are not the only methods which may be employed; however, if other methods are to be used, it must be verified that the value of the characteristics determined by the methods used will fall within the limits specified by the relevant specification when measured by the recommended methods.

6.2 Equilibrium Conditions — All electrical tests shall be conducted under equilibrium conditions unless otherwise specified. When test conditions cause a significant charge with time of the characteristics being measured, means of compensation for such effects should be specified; for example, the period of time that the oscillator shall be maintained at specified test conditions before making a measurement of output frequency.

6.3 Temperature — Unless otherwise specified, all measurements shall be made at an ambient or reference point temperature of 25 ± 2°C. Measurements may be made at other temperatures provided it is verified that the characteristics of the oscillator are in accordance with all the provisions of the detail specification when tested at 25°C.

6.4 Power Supplies — DC power sources used in the testing of crystal controlled oscillators should not have ripple content large enough to affect the desired accuracy of measurement; ac power sources should be transient free. When the ripple and/or transient content of the power sources is critical to the measurement being performed, it must be fully defined in the detail specification.

6.5 Operating Conditions — During electrical testing of quartz crystal controlled oscillators, all power supply voltages and load impedances should be controlled to an accuracy of ±1 percent, unless otherwise stated in the detailed specification.

6.6 Precautions — The measurement circuits and procedures for specific electrical tests given in 9 and the preferred methods and circuits; should measuring apparatus modify the characteristics being examined, due allowance for any loading effects.

6.7 Air Flow Conditions for Temperature Tests-When devices are to be measured at other than 25 ±2°C, adequate air circulation shall be provided to ensure good temperature control.

TABLE 2 SCHEDULE OF ACCEPTANCE TESTS

(Clause 5.3)

TEST	CLAUSE REF	AQL (PERCENT DEFECTIVE)	INSPECTION LEVEL	D/ND
(1)	(2)	(3)	(4)	(5)
GROUP A				
Visual examination (external)	7	1%	II	ND
Dimensions and mass	8			
Sealing (when specified)	10.2			
Voltage proof	9.2			
Insulation resistance	9.1			
*Input power (when applicable)	9.3			
†Amplitude modulation input impedance	9.10.6			
†Frequency modulation input impedance	9.11.5			
Output frequency	9.4			
Load coefficient	9.6.1			
Voltage coefficient	9.6.2			
Frequency/temperature characteristic (when specified)	9.5			
†Frequency stability with thermal transient (when specified)	9.6.3			
‡Frequency adjustment	9.7			
Retrace characteristic (when specified)	9.8			
Oscillator output impedance (when specified)	9.9.3			
Oscillator output voltage	9.9.1			
§Oscillator output power	9.9.2			
Oscillator output waveform (when specified)	9.9.4			
Re-entrant isolation	9.9.5			
Output suppression of gated oscillator	9.9.6			
Amplitude modulation index	9.10.1			
Amplitude modulation sensitivity	9.10.2			
Oscillator modulation index (non-linearity)	9.10.3			

*Applicable only to oscillators with oven temperature control.

†Applicable only to oscillators with a modulated input voltage.

‡Applicable only to oscillators with a frequency adjustment.

§Applicable only to oscillators with a sine wave output signal.

(*Continued*)

TABLE 2 SCHEDULE OF ACCEPTANCE TESTS- *Contd*

TEST	CLAUSE REF	AQL (PERCENT DEFECTIVE)	INSPECTION LEVEL	D/ND
(1)	(2)	(3)	(4)	(5)
*Frequency modulation distortion (non-linearity)	9.11.3			
Amplitude modulation frequency response	9.10.4			
Frequency modulation frequency response	9.11.4			
Pulse amplitude modulation	9.10.5			
Harmonic distortion (when specified)	9.11.6			
Spurious response (when specified)	9.12.1			
Short term frequency stability frequency domain measurements (when specified)	9.13.1			
†Incidental FM on an AM signal	9.10.7			
Frequency modulation deviation	9.11.1			
Frequency modulation sensitivity	9.11.2			
† Stabilization time	9.6.4			
Robustness of terminations	10.1			
GROUPB				
Sub-group 1				
Endurance	11	4%	s 4	D
Robustness of terminations	10.1			
Electromagnetic interference (radiated)	9.14			
Bump	10.5			
Vibration	10.6			
Shock	10.7			
Sub-group 2				
Low air pressure (when specified)	10.9	4%	s 4	D
Climatic sequence	IO.10			
Mould growth	10.13			
Sub-group 3				
Storage temperature	10.14	4%	s 4	D
Harmonic distortion	9.11.6			
Salt mist	10.12			
Acceleration, steady state	10.8			
Sealing (when specified)	10.2			

*Applicable only to oscillators with a sine wave output signal.

† Applicable only to oscillators with a modulated input voltage.

If heat loss due to forced air circulation affects oscillator performance, still air conditions may be simulated by enclosing the oscillator in a draught shield, consisting of a thermally conducting box with internal dimensions such as to provide a clearance of 20 ± 5 mm from all surfaces of the oscillator. The temperature at which measurements are taken under these conditions, unless otherwise stated in the detail specification, is the reference point temperature on the surface of the oscillator package. If a draught shield is used, it must be retained for both high and low temperature tests.

6.8 **Precision of Measurement** — The limits stated in a detail specification are absolute. Tolerances on measurement instruments and methods shall be taken into account when determining actual experimental limits.

Unless otherwise stated in the detail specification, the precision and accuracy of test methods and equipment used for the evaluation of oscillator performance should be at least one order of magnitude (that is, a factor of ten) better than the tolerances to be determined. (For example, a voltmeter accuracy of $\pm 0{\cdot}1$ percent to determine level to a tolerance of ± 1 percent.) Calibrations of test equipment and reference frequency sources shall be traceable to recognized national standards.

6.9 **Stabilization Time** — When energised and loaded as specified in the relevant specification, the stabilized operating conditions are reached when the output frequency stability does not exceed the specified value. The maximum allowable time to reach the stabilization conditions shall be as follows, unless otherwise specified:

a) Non-temperature controlled oscillator	5 minutes
b) Temperature compensated oscillator	30 minutes
c) Oven temperature controlled oscillator	2 hours

7. VISUAL EXAMINATION (EXTERNAL)

7.1 Visual Test A (Initial Examination) — The oscillator shall be visually examined to ensure that the condition, workmanship and finish are satisfactory. The markings shall be legible and durable.

7.2 **Visual Test B (Post-Test Examinatiou)** — The oscillator shall be visually examined. There shall be no corrosion or other deterioration likely to impair satisfactory operation. Markings shall be legible and durable.

8. DIMENSIONS AND MASS

8.1 Dimensional Test A (Terminations) — Dimensions, spacing and alignment of the terminations shall be checked for conformance to the specification, using gauges as specified.

8.2 **Dimensional Test B (Package Dimensions)** — The overall package dimensions shall be checked for conformance to the specification.

8.3 **Mass** — The mass shall be determined for the conformance to the relevant specification.

9. ELECTRICAL TESTS

9.0 The tests specified shall be performed unless specifically excluded in the relevant specification. Test procedures for the determination of the following performance characteristics are included in this document:

a) Insulation resistance (**9.1**),
b) Voltage proof (9.2),
c) Input power (9.3),
d) Output frequency (9.4),
e) Frequency temperature characteristics (9.5),
f) Frequency stability characteristics (9.6),
g) Frequency adjustment (9.7),
h) Retrace characteristics (9.8),
j) Output characteristics (9.9),
k) Amplitude modulation characteristics (**9.10**),
m) Frequency modulation characteristics (**9.11**),
n) Spectral purity characteristics (**9.12**),
p) Short term frequency stability (**9.13**), and
q) Electromagnetic interference characteristics (**9.14**).

9.1 Insulation Resistance

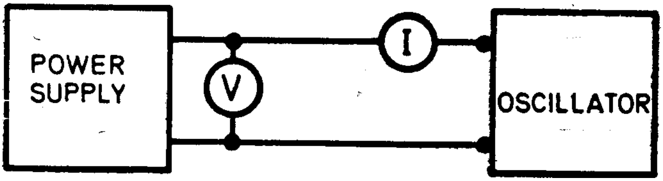
9.1.1 *Purpose* — To determine that the resistance between specified points exceeds a specified value when measured with an applied voltage below the breakdown value.

9.1.2 *Test Circuit* — The test diagram is given in Fig. 1.

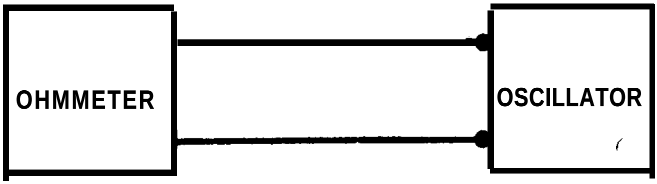
9.1.3 *Description*-*The* specified value is applied between the specified terminals, and the resulting current is measured. Alternatively, an ohm-meter may be used to determine the resistance directly.

9.1.4 *Procedure* — The measurement may be made by the application of the specified voltage and measurement of the resulting current, or by the direct reading of an ohm-meter connected between the specified terminals. Current flow shall be less than the specified maximum. Following this test, operational tests shall be carried out to ensure that the device is functional.

9.1.5 *Precautions* — Voltage should be applied only to the specified terminals, and polarity should be observed when specified. The applied voltage during test should not exceed the specified value. Failure to observe any of the above may result in damage to the device under test.



IA Voltage-Current Method



IB Ohm-Meter Method

FIG. 1 MEASUREMENT OF INSULATION RESISTANCE

9.1.6 *Specified Conditions* — The value of the following shall be stated in the detail specification:

a) Test points,

b) Applied voltage limits and polarity,

c) Minimum resistance, and

d) Maximum current flow.

NOTE - When (b) and (c) are not otherwise stated, maximum voltage shall be less than 20V, and measured resistance shall be greater than 20 MΩ.

9.2 Voltage Proof

9.2.1 *Purpose* — To determine that the application of a high voltage between two or more specified terminals will not produce electrical breakdown or excessive current, or otherwise impair the performances of the oscillator.

9.2.2 *Test Circuit* — The test circuit diagram is given in Fig. 2.

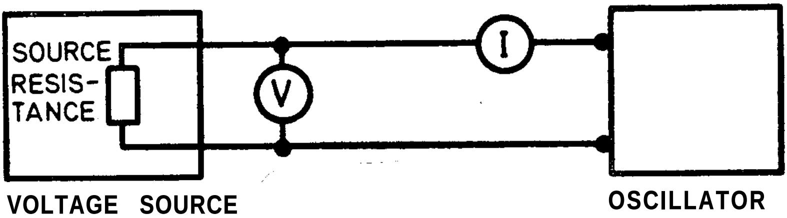


FIG. 2 MEASUREMENT OF VOLTAGE PROOF

9.2.3 *Procedure* — The specified voltage is applied between the designated terminals. There shall be no arcing or the evidence of breakdown. Following this test, operational tests shall be carried out to ensure that the oscillator performance has not been impaired.

9.2.4 ***Precautions***- Voltage should be applied only to the specified terminals, and polarity should be observed when stated. Applied voltage should not exceed specified values, and current flow should not be allowed to exceed stated maximum. Failure to observe any of the above may result in damage to the device under test.

9.2.5 ***Specified Conditions*** — The values of the following conditions will be stated in the detail specification:

a) Test terminals;

b) Applied voltage maximum, and polarity;

c) Source resistance;

d) Maximum permissible current flow; and

e) Preconditioning procedures, if applicable.

9.3 Input Power

9.3.1 ***Purpose*** — To determine supply voltage and input power requirements to the oscillator and oven (when applicable) when operating under specified conditions.

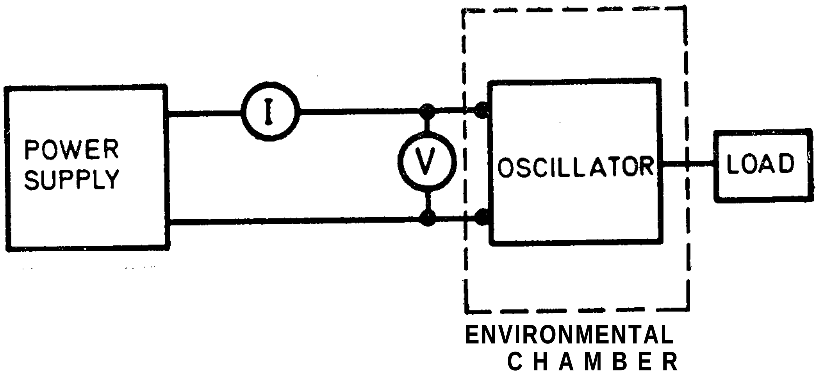
9.3.2 ***Test Circuit Connections*** — The circuit connection is given in Fig. 3.

9.3.3 *Procedure* — Oscillator, electrical load, and power supplie(s) are connected as shown, and supply voltage(s) and current(s) monitored with suitable meters. Supply voltages stated in the detail specification shall be maintained with an accuracy of ± 1 percent unless otherwise specified. Input power is calculated from the measured values of voltage and current:

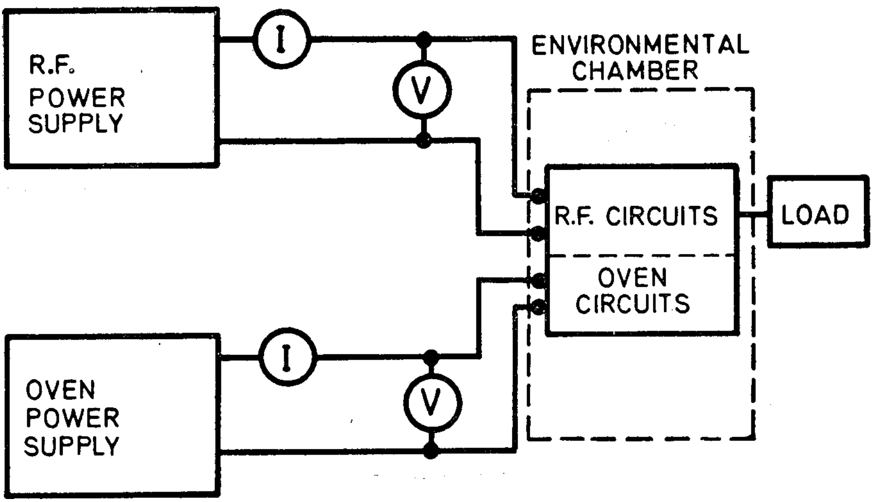
$$P = V \times I$$

When input power measurements are to be made at other than the reference temperature, the device under test shall be placed in a suitable environmental chamber. Measurements at each specified value of temperature shall be made after continuous operation at that temperature for the specified stabilization time.

In the case of oven controlled crystal oscillator (OCXO), both peak and steady-state input power may be specified. If peak power is specified, the transient values of voltage and current shall be measured when the environmental chamber is adjusted to each of the specified temperatures. The oscillator and oven shall be allowed to reach thermal equilibrium at the operating temperature, while unenergized, prior to any measurement of peak power.



3A Single Power Source



3B Separate R.F. and Oven Power Source

FIG. **3** MEASUREMENT OF INPUT POWER

9.3.4 Precautions

a) Where input power to the oscillator will be affected by forced air circulation, still air conditions may be simulated by the use of a draught shield as described in 6.7;

b) If peak power is to be measured, it may be necessary to use recording type meters for the measurement of voltage and current in order to determine transient values with adequate resolution; and

c) The environmental chamber used for measurements at other than reference temperature should have a thermal time constant significantly less than that of the oscillator/oven being measured, when peak power is to be determined.

9.3.5 *Specified Conditions* — The values of the following conditions shall be stated in the detail specification:

a) Voltage(s) of supply;

b) Load details;

c) Temperature(s) at which measurements are to be performed, unless otherwise stated, the temperature will be taken as the reference point temperature on the surface of the oscillator package; and

d) Stabilization time.

NOTE — It should also be stated if a measurement of peak power is to be made.

9.4 Output Frequency

9.4.1 ***Purpose*** — To measure the output frequency of a crystal oscillator under specified operating conditions. The measurement methods described should be used whenever the frequency of an oscillator is to be determined. Two methods are given, the choice depending upon the precision to which the determination is to be made.

9.4.1.1 ***Frequency measurement accuracy less than or equal to*** 1 ***part in*** 10^7

a) ***Test circuit*** — The test circuit diagram is given in Fig. 4A.

b) ***Procedure*** — The oscillator shall be connected as shown and allowed to stabilize under specified operating conditions. The frequency shall then be measured with the frequency counter, using either a direct frequency measurement or a period averaging method. Measurement times in the range of 0·1 to 1 second will normally be required to obtain the required measurement precision. Period averaging will generally be advantageous for frequencies below about 5 MHz.

9.4.1.2 ***Frequency measurement accuracy greater than 1 part in*** 10^7

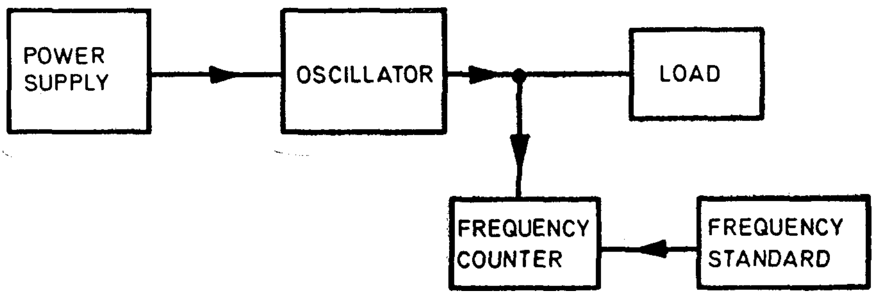
a) ***Test circuit*** — The test circuit diagram is given in Fig. 4B.

b) ***Procedure*** — The oscillator shall be connected as shown and allowed to stabilize under specified operating conditions. A frequency multiplication factor should be chosen which will permit measurement to the specified precision within a time interval in the range from 0·1 to 1 second.

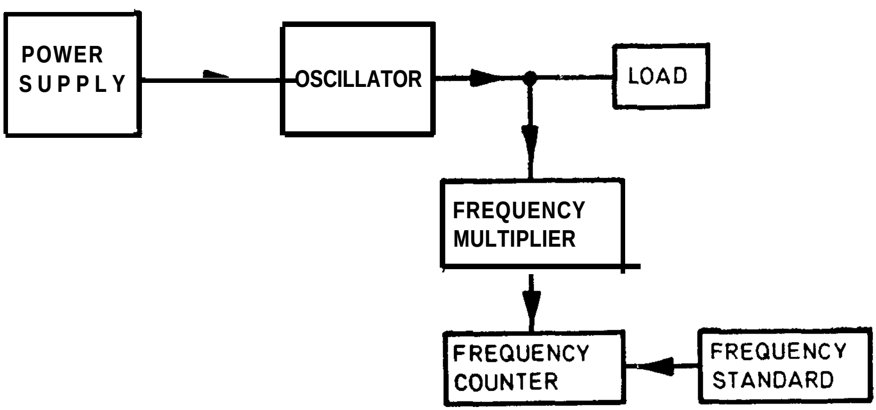
Example :

To measure a 2·5 MHz signal to a precision of 1×10^{-8} within a 10 second interval, a multiplication factor of 4 is required.

NOTE - Alternative methods of measurement include the use of high-speed 'reciprocal' counters, as well as the use of phase comparison systems to determine the frequency difference between the oscillator and a known frequency derived from a frequency synthesizer. This latter method is especially useful for measurement accuracies better than 1×10^{-9}.



4A Counter Method for $\Delta f / f >$ I x IO-’



4B Counter Method for $\Delta f/f <$ I X IO-’

FIG. 4 MEASUREMENT OF OSCILLATOR OUTPUT FREQUENCY

9.4.2 Precautions — Whichever method of measurement is used, the following should be observed:

a) The accuracy and resolution of the measurement system shall always be an order (factor of ten) better than the tolerances placed on the measurement of frequency;

b) The oscillator shall be correctly loaded, including compensation for the test equipment connections;

c) Stability and accuracy of the system must be verified by periodic checks of the frequency standard against a recognized national standard; and

d) Care must be taken that environmental conditions are adequately controlled so as not to influence the results.

9.4.3 Specified Conditions — The following test conditions shall be stated in the detail specification:

a) Power supply voltage(s),

b) Load details,

c) Frequency measurement accuracy,

d) Ambient temperature(s), and

e) Stabilization time.

9.5 **Frequency/Temperature Characteristics**

9.5.1 ***Purpose*** — to determine the dependence of output frequency of a crystal oscillator upon temperature. This test method may be used to determine the ***total frequency excursion*** over a specified operating temperature range, or to determine the ***output frequency at specified particular temperatures.***

9.5.2 Test Circuit — The test circuit diagram is given in Fig. 5.

9.5.3 ***Test Apparatus***

9.5.3.1 The test chamber shall conform to the relevant provisions of IS : 9662 (Part I)-1977* and IS : 9002 (Part II)-1977† except as modified below:

a) The chamber shall be capable of maintaining high and low temperature in working space as specified in the relevant specification;

b) The temperature shall be maintained at any point in the chamber over the entire temperature range within a tolerance of 1°C;

c) If provision for forced air circulation is made to maintain homogeneous condition within the chamber, the air flow shall be of forced laminar air-flow technique with circulation rate of 60 ± 30 m per minute;

d) The temperature gradient between air input and air-exhaust shall be less than 1°C;

***Specification for equipment for environmental tests for electronic and electrical items : Part I Chamber for cold test.**

†Specification for equipment for environmental tests for electronic and electrical items : Part II Chamber for dry heat test.

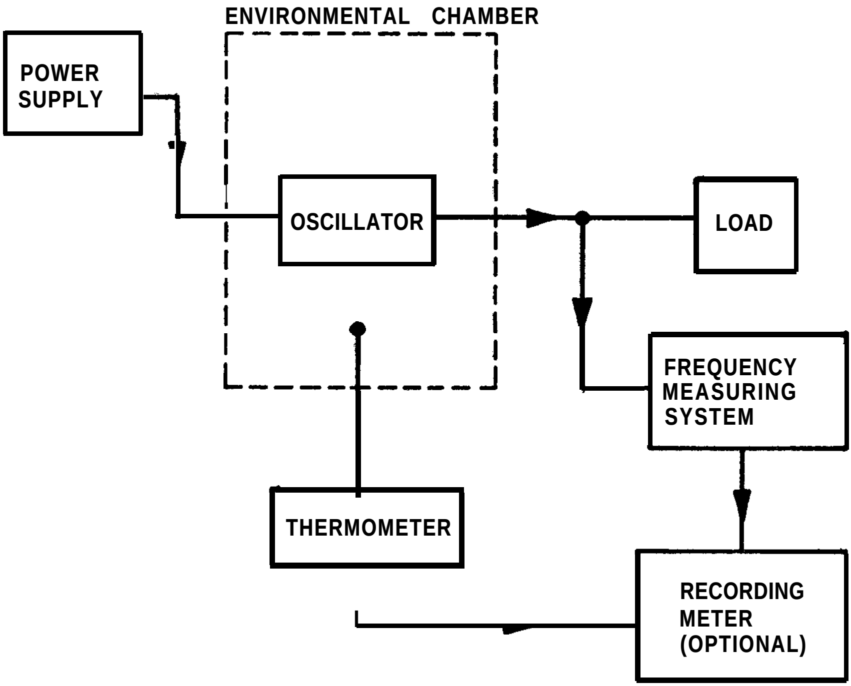


FIG. 5 MEASUREMENT OF FREQUENCY-TEMPERATURE CHARACTERISTICS

e) A minimum of two temperature sensing devices shall be in the test chamber for temperature gradient measurement at reference points; and

f) For ramped temperature tests, the rate of change of temperature should be less than 0·5°C per minute, unless otherwise stated in the relevant specification.

When the oscillator under test is a TCXO type, special care must be taken to ensure a slow rate of temperature change. Unless otherwise stated in the relevant specification, stabilization time of 1 hour and the temperature ramped rate should be less than 0·2°C per minute.

9.5.3.2 The temperature measuring devices should meet the following requirements:

a) A thermometer preferably of digital type with an accuracy of 0·5°C over the specified ambient temperature range of the oscillator and a resolution of 0·1°C shall be used;

b) There shah be a minimum of two temperature sensing devices which are matched within 0·25°C at any point of the specified ambient temperature of the oscillator. Any additional temperature sensing device shall be matched to the first pair to the same accuracy; and

c) The output of the temperature sensing device shall be sufficient to drive a printer.

9.5.3.3 A printer of digital recorder or XY plotter with the following characteristics should be used:

a) The printer shall print temperature values and frequency values simultaneously and versus each other, and

b) The printing rate and resolution shall commensurate with the accuracy required.

9.5.4 ***Procedure*** — The unenergized oscillator shall be connected as shown, and the environmental chamber allowed to reach equilibrium at the lowest specified temperature. The oscillator shall then be energized; after the specified stabilization time, frequency and temperature shall be recorded, using a frequency measurement method in accordance with 9.4.

The test chamber temperature shall then be raised in incremental steps (or ramped at a specifed rate) allowing the specified stabilization time at each temperature setting.

NOTE — In some applications, it may be required to determine the reproducibility of the frequency-temperature characteristic as the temperature is first increased from minimum to maximum, then decreased from maximum to minimum. Differences in the characteristics obtained during increasing and decreasing temperatures are called *retrace errors*, or hysteresis, and are of particular importance when testing TCXO devices.

9.5.5 Frequency/Temperature Curve — Continuous recording/plotting of temperature and frequency during this test may be specified in order to ensure that the frequency never exceeds specified tolerances.

9.5.6 ***Precautions***

a) Where input power to the oscillator will be affected by forced air circulation, still air conditions may be simulated by the use of a draught shield as described in 6.7;

b) If specific temperatures are not given for discrete temperature measurements, incremental steps should not exceed 1·5°C, with suitable stabilization time after each setting of environmental temperature;

c) The time allowed for the oscillator to stabilize should always exceed the stabilization time by a factor of 2·1 unless otherwise stated in the detail specification; and

d) When the oscillator under test is a TCXO type, lower temperature ramped rates [see 9.5.3.1(f)] and stabilization time of one hour should be used.

9.5.7 ***Specified Conditions*** — The following test conditions shall be stated in the detail specification:

a) Power supply voltage(s),

b) Load details,

c) Frequency measurement accuracy,

d) Temperature test range,

e) Maxi-mum rate of change of temperature,

f) Temperature steps and stabilization time for incremental method of measurement, and

g) Other items in accordance with the relevant specification.

9.6 Frequency Stability Characteristics

9.6.1 ***Determination of Load Coefficient***

9.6.1.1 Purpose — to measure the change in output frequency as a function of change in load.

9.6.1.2 ***Procedure*** — Measurements of oscillator output frequency shall be made by the frequency measuring system specified in 9.4 for the specified nominal load conditions, minimum load conditions, and maximum load conditions. All other operating parameters shall be maintained constant at their specified values during measurement.

9.6.1.3 ***Precautions*** — Any connections made to the output terminals of the oscillator to measure frequency shall be included in the total electrical load value.

9.6.1.4 ***Specified conditions*** — The following test conditions shall be stated in the detail specification:

a) Power supply voltage(s),

b) Nominal load (resistance and reactance as appropriate),

c) Minimum and maximum load limits,

d) Frequency measurement accuracy,

e) Nominal frequency, and

f) Stabilization time.

NOTE — The use of an accurately controlled environmental test chamber may be required to reduce the effects of temperature changes on measured values of frequency deviation.

9.6.2 Frequency Change as a Function of Supply Voltage(s) (Voltage Coefficient)

9.6.2.1 Purpose — to determine the change-in oscillator output frequency as a function of variation in the power supply voltage.

9.6.2.2 ***Procedure*** — Measurements of oscillator frequency shall be made by the frequency measuring system specified in 9.4 adjusting the power supply voltage to its specified nominal value, to its minimum value; and to its maximum value. All other operating parameters shall be maintained at their specified values. In all cases, the specified stabilization time shall be allowed between adjustment of supply voltage and measurement of frequency.

9.6.2.3 ***Precautions*** — A transient frequency excursion may occur immediately after adjustment of the power supply voltage, particularly if the device under test is either an OCXO or TCXO type. If the magnitude of this transient excursion is of importance, recording type meters should be used to record the frequency excursion, and the maximum permissible deviations during the transient interval should be separately specified.

The use of an environmental test chamber may be required to maintain the ambient temperature at its specified value during the performance of this test.

9.6.2.4 ***Specified conditions*** — The following test conditions shall be stated in the detail specification:

a) Nominal load,

b) Temperature (if different from the reference temperature),

c) Nominal supply voltage(s),

d) Minimum and maximum supply voltages,

e) Frequency measurement accuracy, and

f) Stabilizaion time.

9.6.3 Frequency Stability with Thermal Transient

9.6.3.1 ***Purpose*** — to measure the thermal response time and ***overshoot*** of the transient frequency excursion of an oscillator resulting from a specified temperature change.

9.6.3.2 ***Test circuit*** — The test circuit diagram is given in Fig. 5.

9.6.3.3 ***Procedure-The*** oscillator shall be placed in the environmental chamber and allowed to reach equilibrium at the specified initial temperature T_1. The oscillator shall then be energized and allowed to stabilize for the specified time interval under normal operating conditions. At the end of this period, the environmental temperature shall be changed at the specified rate to the final temperature, T_2. The oscillator output frequency and the environmental temperature (are measured at the reference point on the oscillator case) should be continuously recorded during and after this operation, resulting in a plot of both frequency change and

temperature similar to that in Fig. 6, from which the ***thermal response time*** and the ***overshoot*** may be determined:

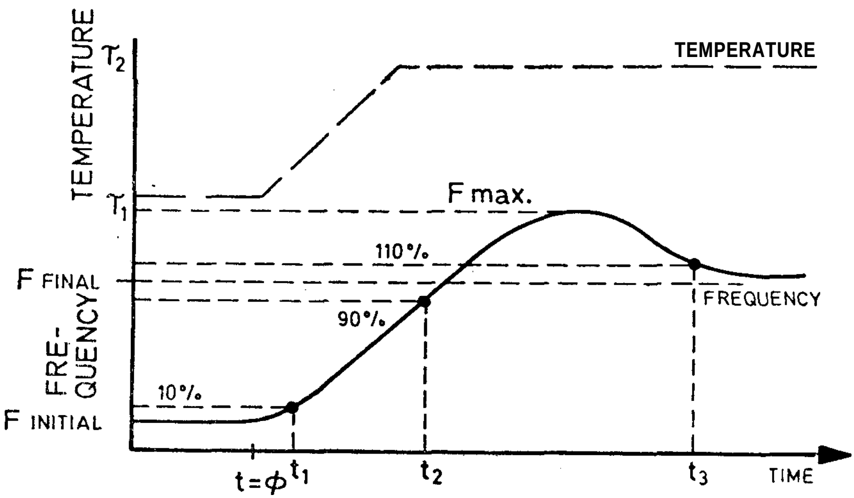
a) The ***overshoot*** of the transient excursion may be specified either in fractional parts of the nominal frequency (that is, the overshoot should not exceed 2 x 10^{-7}), or as a percentage of the steady-state frequency offset, that is, according to the relation:

$$\text{Overshoot (percentage)} = \frac{F_{max} - F_{final}}{F_{final} - F_{initial}} \times 100; \text{ and}$$

b) Unless otherwise specified, the ***thermal response time*** is the time interval between the instant the frequency has changed 10 percent of the overall change, and the instant the frequency has attained a value within 10 percent (of the change) of its final frequency. There are two possible cases, as shown by the sample recordings in Fig. 6.

1) When the overshoot is less than 10 percent, the thermal response time $= t_2 - t_1$ *Min.*

2) When the overshoot is equal to or greater than 10 percent, the thermal response time $= t_3 - t_1$ *Min.*



$t = \phi$ = end of stabilization time.

t_1 = time for frequency to change 10% of the steady state increment.

t_2 = time for frequency to change 90% of the steady state increment.

t_3 = time for frequency to reach 110% of the steady state increment on the recovery from overshoot (in the case where overshoot is greater than 10%).

FIG. 6 THERMAL RESPONSE TIME AND OVERSHOOT

9.6.3.4 *Precautions*

a) The temperature sensor should be positioned so as to record the reference-point temperature at the specified location on the oscillator case. Both sensor location and temperature ramp shall be accurately defined in order to obtain reproducible results.

b) Response time of the frequency measuring system (whether analog or digital) shall be short compared to the maximum rate of change of frequency exhibited by the oscillator under test.

Specified Conditions — The following test conditions shall be stated in the detail specification:

a) Power supply voltage;

b) Load details;

c) Frequency measurement accuracy;

d) Initial and final reference-point temperatures, and the rate of change of reference-point temperature for purposes of test; and

e) Precise locations of temperature sensor reference point.

9.6.4 *Stabilization Time*

9.6.4.1 *Purpose* — to measure the time taken for an oscillator to stabilize within specified limits under stated conditions.

9.6.4.2 *Circuit* — The circuit diagram is given in Fig. 5.

9.6.4.3 *Description* - This test is to measure the time taken for the oscillator output frequency to stabilize within specified limits after the initial application of power. The frequency measurement system is as specified in 9.4.

9.6.4.4 *Procedure* — The unenergized oscillator shall be placed in the environmental' chamber and the temperature adjusted to that specified. The oscillator shall then be energized and the output frequency registered on the recording meter as a function of time.

Figure 7 shows a typical plot of output frequency after 'turn-on'. The stabilization time (t_s) is the time that is taken for the output frequency to reach its long term value within the frequency tolerance specified.

9.6.4.5 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Voltage of supply,

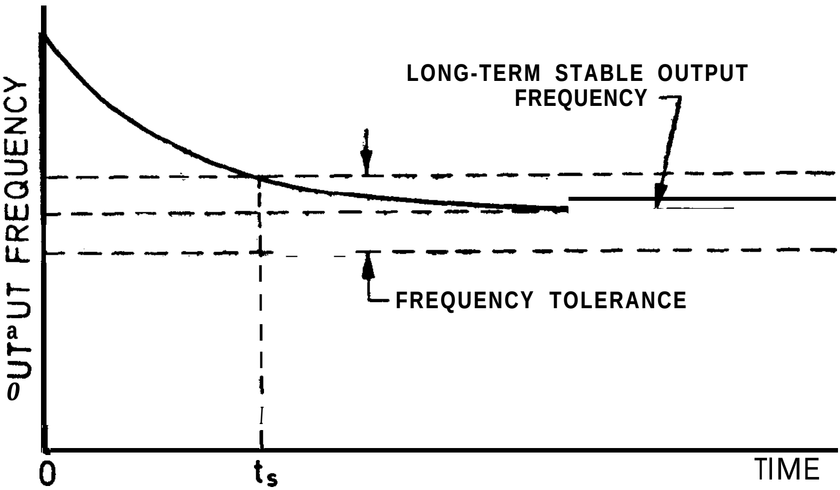
b) Load details,

c) Frequency measurement accuracy,

d) Specified temperature(s), and

e) Frequency tolerance.

NOTE — It is normal to specify the limits as those applying to the frequency excursion over the temperature range.



Fro. *7* TYPICAL OUTPUT **FREQUENCY**

Example:

> **If an oscillator is specified to have maximum frequency excursion of $\pm 2_{pp} 10^{\bullet}$ over the temperature range, then the stabilization time would be the time taken to come within these limits at any specified operating temperature.**

9.7 Frequency Adjustment and/or Settability

9.7.1 ***Purpose*** — to measure the range and/or settability of frequency adjustment.

9.7.2 ***Test Circuit*** — The test circuit diagram is given in Fig. 4.

9.7.3 ***Description*** — This test is to determine the range of frequency variation available. The frequency adjustment range will normally be expressed as a fractional deviation from nominal frequency that is $\pm 1 \times 10^{-4}$ minimum.

9.7.4 ***Procedure*** — The output frequency shall be measured at the specified adjustment conditions by the frequency measuring system specified in 9.4.

9.7.5 ***Precautions-The*** accuracy and resolution of the measurement system shall be an order better than the specified frequency adjustment range to be determined.

The effects of the measurement system shall be included in determining the specified load conditions on the oscillator.

Stability and accuracy of the measurement system shall be periodically verified against a recognized national standard.

9.7.6 *Specified Conditions* — The following test conditions shall be stated in the detail specification:

a) Supply voltage,

b) Load details,

c) Frequency measurement accuracy, and

d) Stabilization time.

NOTE — Unless otherwise specified, the frequency adjustment range shall normally be taken as the extremes of the range available.

9.8 Retrace Characteristics

9.8.1 *Purpose* — to measure the ability to return to within specified limits of a previously stabilized frequency, following a storage period in an unenergized condition.

NOTE-The term 'Retrace Characteristic' has another meaning when used in connection with the performance of TCXO's, as stated in 9.5. The measurement described here is usually specified for OCXO's or PXO's.

9.8.2 *Test Circuit* — The test circuit diagram is given in Fig. 8.

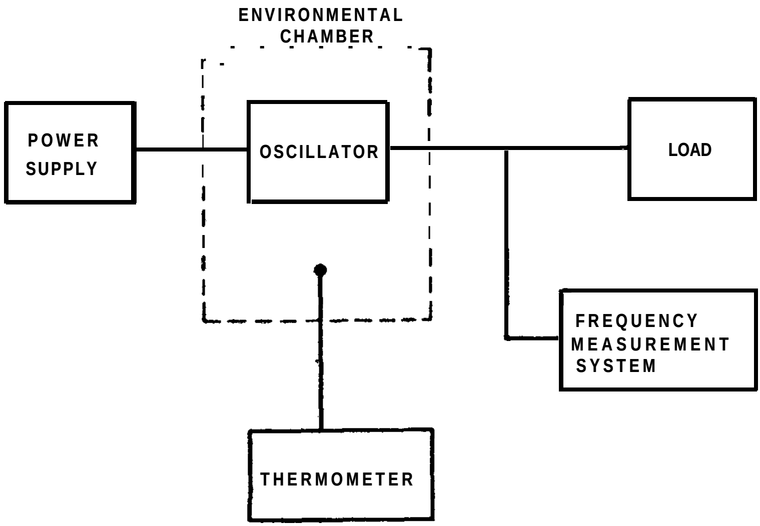


FIG. 8 DETERMINATION OF RETRACE CHARACTERISTICS

9.8.3 Description — This test is to measure the output frequency of an oscillator after a specified storage period (or periods) in an unenergized condition, compared to its long-term stabilized value before turn-off. For purposes of this test, all operating conditions during preliminary stabilization should be carefully noted, and accurately restored after the specified unenergized storage period.

NOTE — The test is not to determine stabilization time, (see 9.6.2) which generally refers to shorter periods of time and considerably wider tolerances.

9.8.4 Procedure — The unenergized oscillator shall be placed in the environmental chamber and the temperature maintained to that specified. The oscillator shall be energized, and all operating parameters adjusted to specified values, after which the frequency shall be measured as a function of time. Following a specified period of operation (t_1) Fig. 9, which shall exceed the stabilization time, the output frequency shall be recorded. The oscillator is then turned off, and allowed to assume the storage temperature for the specified time period (t_2). At the end of the storage period, power is again applied, and frequency recorded as a function of time. The retrace time (t_r) is the time period following application of power required for the output frequency to return to within the specified tolerance of the value recorded before turn-off.

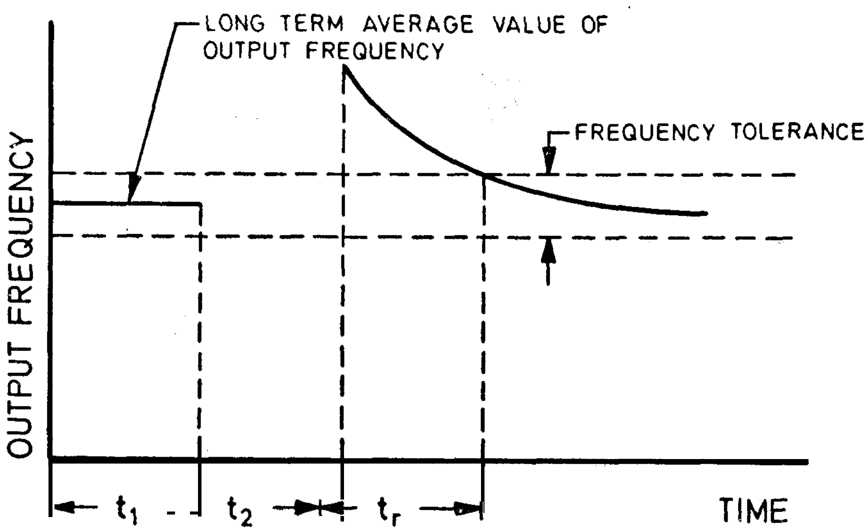


FIG. 9 RETRACE CHARACTERISTICS

9.8.5 Precautions — If the oscillator is stored (during period t_2) in other than the environmental chamber, adequate time shall be allowed for the oscillator to settle to the temperature specified for frequency measurement,

before any measurement of frequency takes place; this stabilization time (in an unenergized condition) should be taken as a part of the storage period (t_2).

9.8.6 Specified Conditions — The values of the following test conditions shall be stated in the detail specification:

a) Voltage(s) of supply,

b) Load details,

c) Frequency measurement accuracy,

d) Measurement temperature,

e) Time for the oscillator to settle prior to the first measurement of retrace (t_1),

f) Storage interval(s) (t_2),

g) Storage temperature, and

h) Frequency tolerance.

NOTE — Provision is given for a separate specification of measurement temperature and storage temperature as, although they may indeed be the same temperature, the tolerance on the storage temperature may be considerably greater than that of the measurement temperature which would typically be 25 ±0·5°C.

9.9 Output Characteristics

9.9.1 *Oscillator Output Voltage*

9.9.1.1 *Purpose-to* measure the output voltage of the oscillator when operating under specified conditions.

9.9.1.2 *Circuit* — The circuit diagram is given in Fig. 10.

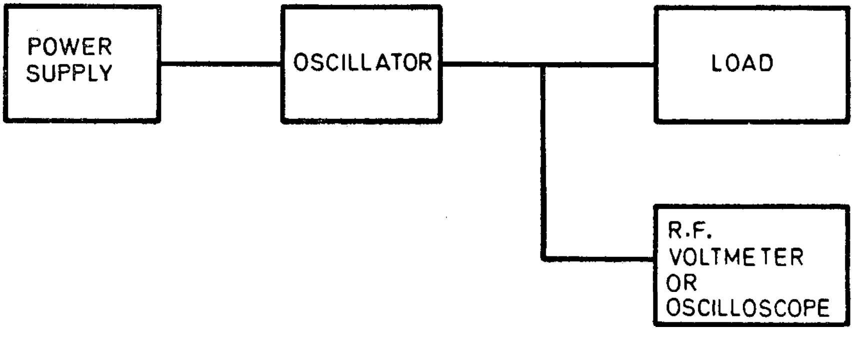


FIG. 10 MEASUREMENT OF OUTPUT VOLTAGE, OUTPUT POWER AND OUTPUT IMPEDANCE

9.9.1.3 *Procedure* — The oscillator circuit is connected as shown in Fig. 9. The output voltage is monitored and shall remain with the specified limits over the range of any frequency adjustment available. This measurement is normally performed at 25°C, but may be specified over the operating temperature range.

a) ***RMS voltage*** — The rms output voltage shall be measured across the load with an rf voltmeter.

b) ***Peak-to-peak voltage*** — The peak-to-peak output voltage shall be measured across the load with an oscilloscope,

9.9.1.4 ***Precautions*** — For non-sinusoidal output waveforms, care shall be taken in expressing the value of rms output voltage as read on meters not working on the 'true rms' principle.

9.9.1.5 ***Specified conditions*** — The values of the following test conditions shall be stated in the detail specification:

a) Voltage or supply,

b) Load details, and

c) Stabilization time.

9.9.2 ***Oscillator Output Power***

9.9.2.1 Purpose — to measure the output power of the oscillator when operating under specified conditions.

9.9.2.2 ***Procedure*** — The measurement circuit, specified conditions etc are exactly as for 9.9.1 (output voltage). The output power is calculated from the rms output voltage and a knowledge of the load impedance or, alternatively, it may be read directly from an appropriate power meter. In the case of non-sinusoidal waveforms, the measurement of output power should always be performed by a direct reading power meter or by means of a 'true rms' reading voltmeter.

9.9.3 ***Oscillator Output Impedance***

9.9.3.1 Purpose — to determine the oscillator output impedance when operating under specified conditions.

9.9.3.2 ***Circuit*** — The circuit diagram is given in Fig. 10.

9.9.3.3 ***Procedure*** — The oscillator is connected as shown in Fig. 10 and the output impedance determined in the following manner:

a) Load the oscillator with a precision (± 1 percent non-reactive) resistor R_L, equal to the specified load minus 10 percent;

b) Measure output voltage V_L;

c) Load the oscillator with a precision ($\pm$ 1 percent non-reactive) resistor R_H , equal to the specified load plus 10 percent;

d) Measure output voltage V_H; and

e) Calculate output impedance

$$Z = \frac{R_L R_H \times (V^2_H - V^2_L)}{V^2_L R_H - V^2_H R_L}$$

9.9.3.4 Specified conditions — The values of the following test conditions will be stated in the detail specification:

a) Voltage of supply, and

b) Load details.

9.9.4 ***Oscillator Output Waveform***

9.9.4.1 ***Purpose*** — to determine the oscillator output waveform when operating under specified conditions.

9.9.4.2 ***Circuit*** — The circuit diagram as given in Fig. 11.

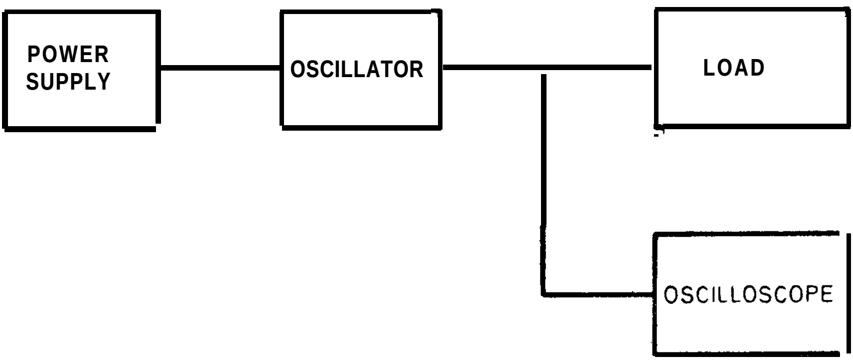


FIG. 11 DETERMINATION OF OUTPUT WAVEFORM

9.9.4.3 Procedure — The oscillator is connected as shown in Fig. 11 and the output waveform displayed on the oscilloscope.

For output pulse waveforms, the rise and fall times, pulse duration and symmetry, may be determined in the following manner (see Fig. 12):

a) ***Output pulse waveform***

1) ***Rise and fall times*** — The rise and fall times of the output pulse of the oscillator shall be measured with an oscilloscope. Measurements are made on the leading and trailing edges at the 10 percent and 90 percent points as referenced to the flat portion of the maximum amplitude level. Overshoot shall be disregarded in this measurement if its peak does not exceed the limits specified for the steady state levels, or the cause for the overshoot can be traced to inductances external to the oscillator

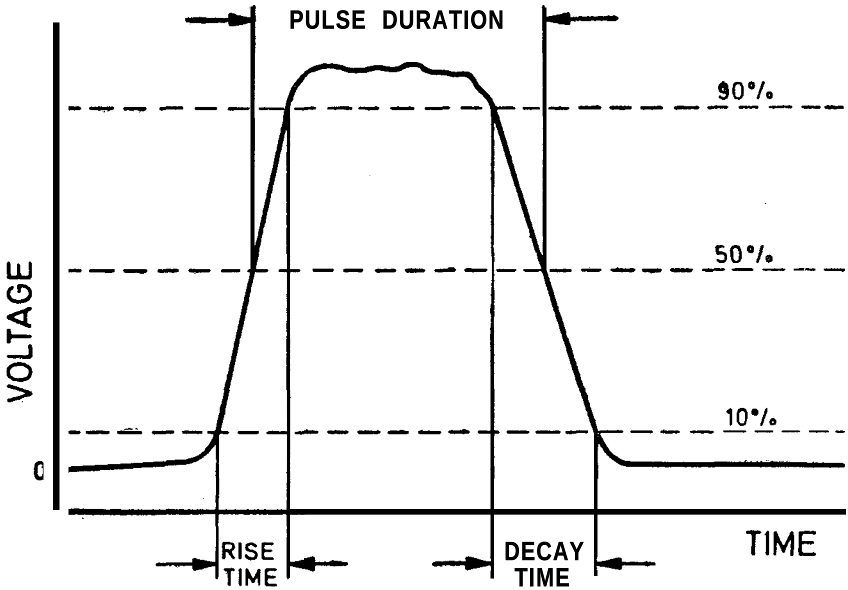


FIG. 12 PULSE OUTPUT WAVEFORM

and oscilloscope. Where higher accuracies are required, the following correction formula shall be used:

$$t_a = \sqrt{(t_1)^2 - (t_s)^2}$$

where

t_a = actual time,

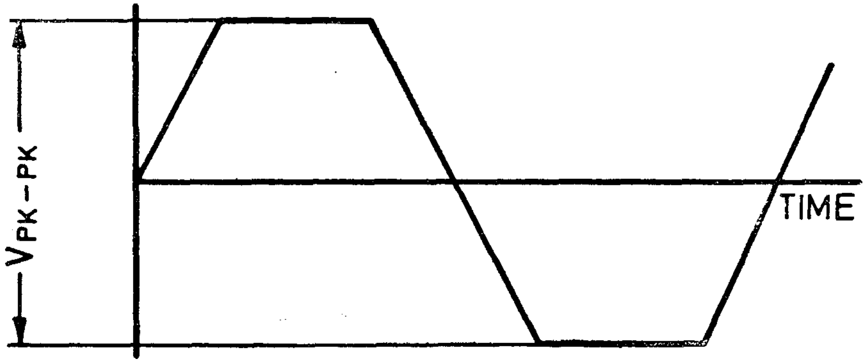
t_1 = measured rise or decay time, and

t_s = oscilloscope rise or decay time.

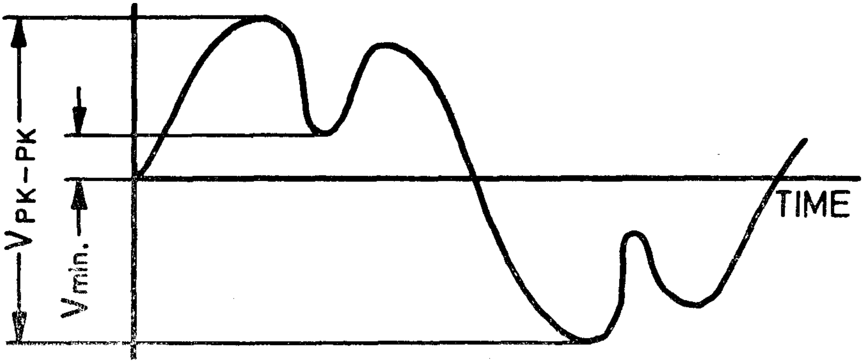
2) (a) *Pulse duration* — The pulse duration of the oscillator shall be measured with the oscilloscope. Unless otherwise specified, measurements are to be made at the 50 percent level as referenced to the maximum amplitude level.

b) *Symmetry* — *The* symmetry of the pulse or square wave output waveform from the oscillator may be specified and should be determined at the time the rise and fall times are measured,

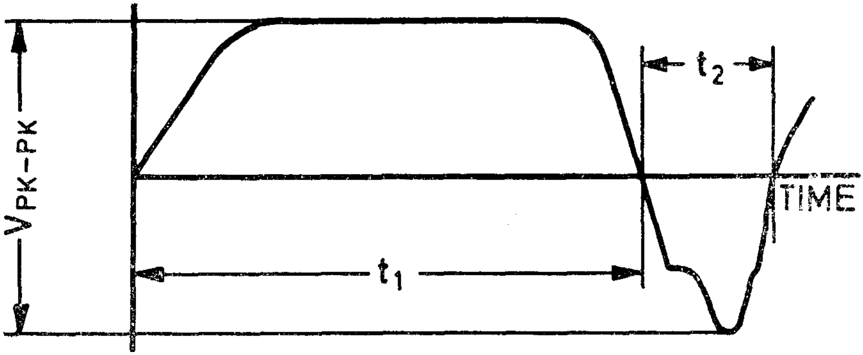
c) Quasi - *sinusoidal waveforms* — Figure 13A shows a typical symmetrical quasi-sinusoidal waveform. The peak-to-peak voltage shall be taken as that voltage measured at the extreme waveform limits as illustrated in Fig. 13A, 13B and 13C.



13A Symmetrical



13B Large Odd-Harmonic Content



13C Large Even-Harmonic Content

FIG. **13** QUASI-SINUSOIDAL WAVEFORM

Figure 13B illustrates a waveform with a large odd harmonic content and may be specified by a voltage limit V_{min}, that is, V_{min} may become negative, and be specified as such.

Figure 13C illustrates a waveform with an excessive even harmonic content (leading to asymmetry) and may be specified by a maximum limit on $\frac{-t_1}{-t_2}$

d) *Logic level outputs* — Figure 14 shows a typical output waveform from an oscillator having TTL logic output. The values of the high and low states of the output may be specified, as well as the details of the waveform. For example, a TTL output might call for V_H to be $+2{\cdot}5$ volts minimum, V_L to be $0{\cdot}23$ volts maximum, the high to low transition time to be 4 ns maximum, and the duty cycle to be 50 $\pm$ 5 percent.

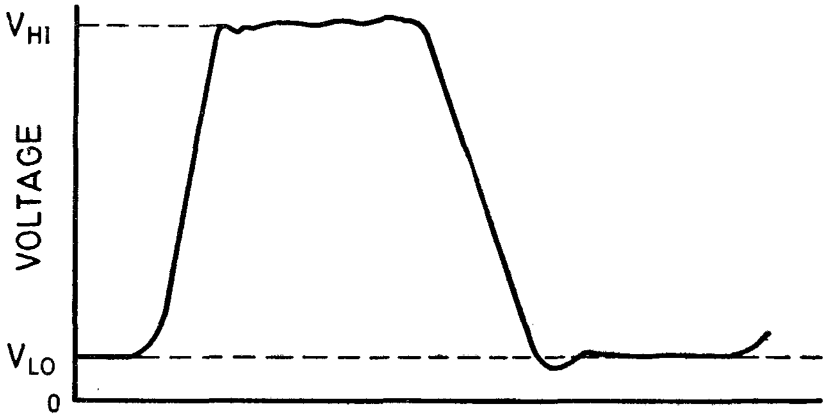


FIG. 14 TYPICAL OUTPUT WAVEFORM

9.9.4.4 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Voltage(s) of supply, and

b) Load details.

NOTE — In the case of logic level outputs, the specified load may be an arrangement of diodes, etc, to simulate the parallel inputs of a number of logic gates.

9.9.5 Re-entrant Isolation

9.9.5.1 *Purpose* — to measure the isolation between output ports of an oscillator having two or more outputs.

9.9.5.2 *Circuit* — The circuit diagram is given in Fig. 15.

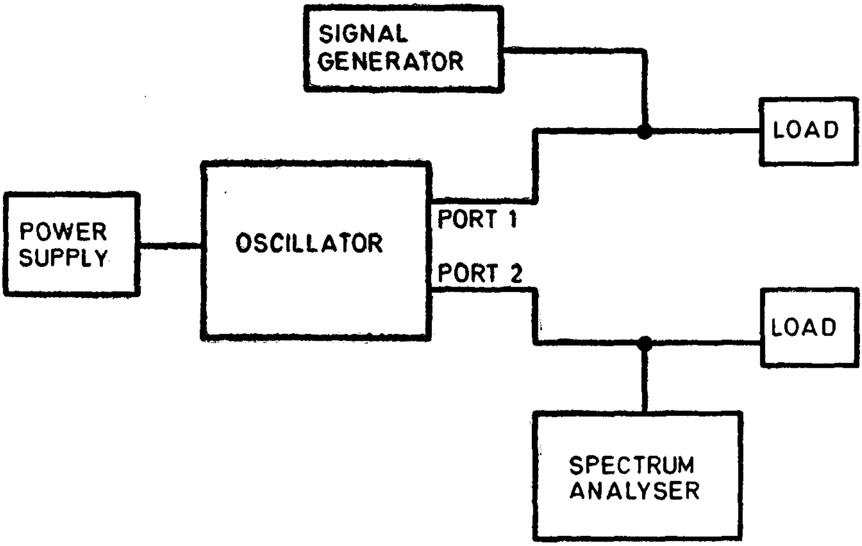


FIG. 15 DETERMINATION OF ISOLATION OF OUTPUTS

9.9.5.3 ***Description-This*** test is designed to demonstrate that the level of an external signal applied to one port is attenuated, to a specified degree, when measured at another output port from the oscillator.

9.9.5.4 ***Procedure*** — The oscillator is connected as shown in **Fig. 15:**

a) Ports between which the isolation is to be measured are shorted together. The level and frequency of the reentrant signal are set on the signal generator as specified. Using a spectrum analyzer (or selective voltmeter), the level of this signal is measured at the port to which the signal is not being applied (or in the case of oscillators with multiple output ports, it is measured at the port specified);

b) The shorting link is removed. The output level is measured as before; and

c) The ratio of the two signals measured with and without the shorting link (usually expressed in dB) is the re-entrant isolationbetween the appropriate ports, at the frequency.

9.9.5.5 Precautions

a) The loads presented to the oscillator will be a combination of the output impedance of the signal generator, the input impedance of the spectrum analyzer (or selective voltmeter and any externally applied loads);

b) Care shall be taken to prevent overloading of the spectrum analyzer (or selective voltmeter) as this will cause signal limiting and an apparent reduction in m-entrant isolation; and

c) If isolation is to be measured at a frequency which is a harmonic of the oscillator, then a pessimistic value of re-entrant isolation will be obtained. However, if the harmonic level is considerably lower than the isolation to be measured, a usable result can still be achieved. Where the harmonic content of the output signal is high, it will be necessary to disable the oscillator (that is, cause the device to cease oscillation while still remaining energized) before measurements can be made.

9.9.5.6 ***Specified conditions*** — The value of the following test conditions shall be stated in the detail specification:

a) Voltage(s) of supply,

b) Load details,

c) Measurement frequency(ies), and

d) Level of test signal.

9.9.6 ***Output Suppression of Gated Oscillators***

9.9.6.1 ***Purpose*** — To measure the reduction in output level of an oscillator unit when the output stage(s) is(are) cut off by a gating signal, the oscillator stage remaining in operation.

9.9.6.2 ***Circuit-The*** circuit diagram is given in Fig. 16.

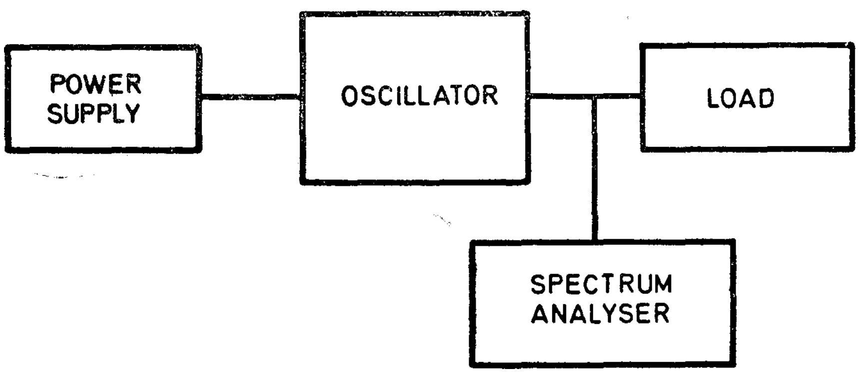


FIG. 16 MEASUREMENT OF REDUCTION IN OUTPUT

9.9.6.3 ***Procedure*** — The circuit is set up as shown in Fig. 16 and the tests carried out as follows:

a) The specified signal necessary to gate the output of the oscillator 'ON' shall be applied, and the level of the output as its fundamental

frequency, and at any harmonic frequency(ies) as specified, measured on the spectrum analyzer;

b) The specified signal necessary to gate the output of the oscillator 'OFF' shall then be applied, and the new output level(s) noted; and

c) The output suppression at a particular frequency is the ratio of the output levels in the 'ON' and 'OFF' states, usually expressed in decibels.

9.9.6.4 ***Precautions*** — Care shall be taken to prevent overloading of the spectrum analyzer as this will cause signal limiting and an apparent reduction in output suppression.

9.9.6.5 ***Specified conditions*** — The values of the following test conditions shall be stated in the detail specification:

a) Voltage(s) of supply,
b) Load details,
c) Measurement frequency(ies), and
d) Details of 'ON' and 'OFF' gating signals.

9.10 Amplitude Modulation Characteristics

9.10.1 ***Amplitude Modulation Index***

9.10.1.1 ***Purpose*** — to measure the modulation index ***(m)*** of an amplitude modulated signal.

9.10.1.2 ***Description*** — This test is to determine the depth of modulation of an amplitude modulated signal. Test A is particularly suitable for a large depth of modulation, while Test B is for a modulation depth of 10 percent or less.

9.10.1.3 ***Modulation index greater than 0·1 and less than 1·0***

a) ***Circuit*** — The circuit diagram is given in Fig. 17A.

b) ***Procedure*** — The output signal of the oscillator shall be displayed on an oscilloscope. The modulation index is determined from the minimum and maximum amplitude as measured from the oscilloscope trace (see Fig. 17B).

c) ***Precaution*** — This method should not be used when $m < 0·1$ because of inherently low measurement accuracy.

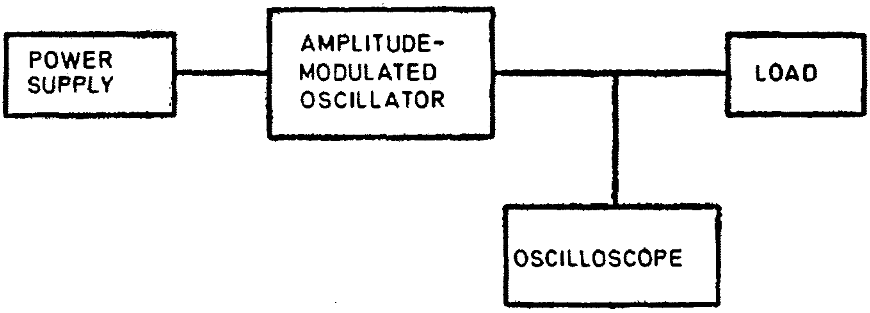
d) ***Specified conditions*** — The values of the following test conditions shall be stated in the detail specification:

a) Load details, and
b) Frequency of modulating signal.

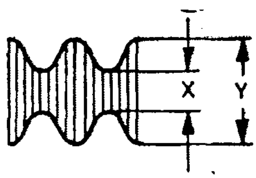
NOTE 1 — The accuracy of this method is unaffected by de presence of frequency modulation.

NOTE 2 — This method is valid for non-sinusoidal waveforms,

NOTE 3 — Modulation depth = 100 m percent.



17A



17B

Modulation Index $m = \frac{Y - X}{Y + X}$: ($m > 0 \cdot 1$)

FIG. 17 MEASUREMENT OF MODULATION INDEX GREATER THAN 0·1 AND LESS THAN 1·0

9.10.1.4 *Modulation index less than* 0·1

a) *Circuit* — The circuit diagram is given in Fig. 18A.

b) *Procedure* — The output signal of the oscillator shall be connected to a spectrum analyzer adjusted to present a display of the frequency spectrum in the region of the output frequency of the oscillator, using a logarithmic signal amplitude scale, as shown in Fig. 18B.

where

f_o is oscillator output frequency.

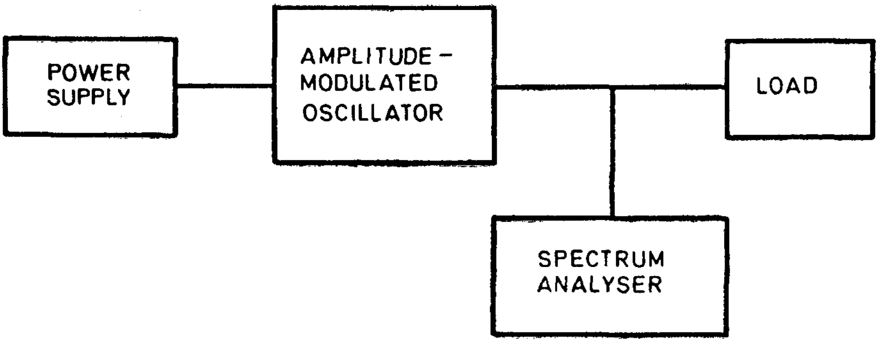
f_m is frequency of modulating signal.

$f_o - f_m$ is lower sideband signal frequency.

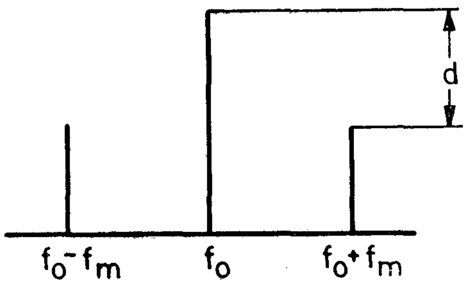
$f_o + f_m$ is upper sideband signal frequency.

$$\text{Modulation Index } m = \log_{10}^{-1}\left[\frac{6-d}{20}\right] (m \not> 0 \cdot 1),$$

where d is the difference between the oscillator output signal frequency (f_o) level and the level of either of the sideband signals in decibels.



18A



18B

FIG. 18 MEASUREMENT OF MODULATION INDEX LESS THAN 0·1

c) *Precautions* — A spectrum analyzer i.f. bandwidth sufficiently low to provide adequate discrimination between the oscillator output and its sideband signals must be used.

Care shall be taken to prevent overloading of the spectrum analyzer causing signal limiting.

d) *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

1) Load details, and

2) Frequency of modulating signal.

NOTE 1 — This method cannot readily be used if significant resultant frequency modulation is present (*see* **9.10.7**) usually causing the two sideband signals to be unequal in amplitude. The effect of the resultant f.m. on the spectrum analyzer display

may be reduced by choosing a high modulating signal frequency (frequency modulation index $B \approx \frac{1}{f_m}$).

NOTE 2 — This method may not readily be used if the modulation waveform is non-sinusoidal, whether because of harmonic content in the modulating signal or because of a.m. non-linear distortion (*see* **9.10.3**).

9.10.2 *Amplitude Modulation Sensitivity*

9.10.2.1 *Purpose* — To measure the modulation index of the amplitude modulated signal resulting from the application of a specified signal to the external modulation terminal of the oscillator.

9.10.2.2 *Circuit* — The circuit diagram is given in Fig. 19.

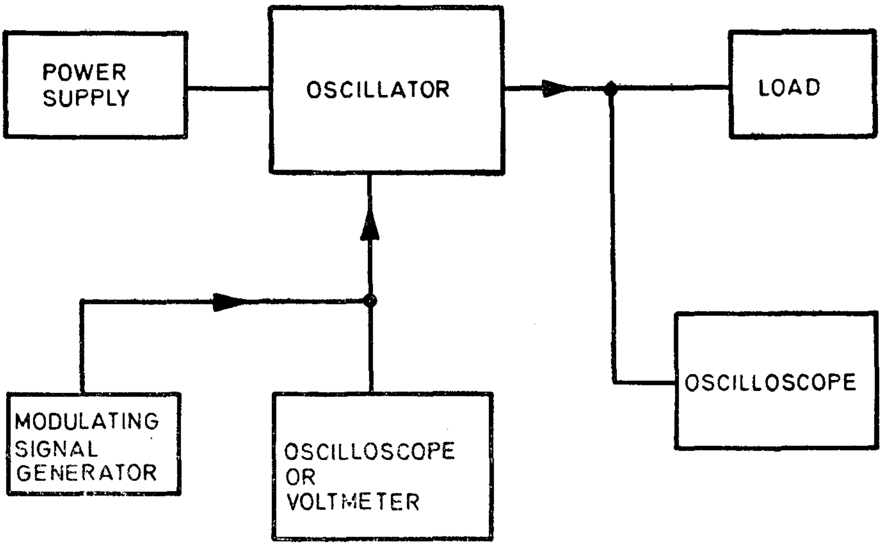


FIG. 19 MEASUREMENT OF AMPLITUDE MODULATION SENSITIVITY

9.10.2.3 *Procedure* — A signal generator providing a modulating signal at the specified frequency shall be connected to the external modulation terminal of the oscillator, and its output set to the specified amplitude as measured by the oscilloscope or valve voltmeter. The modulation index of the output signal shall be measured as described in **9.10.1**. In general, the amplitude modulation sensitivity is defined as the ratio

$$\frac{\text{Modulation index in percent}}{\text{Peak-to-peak modulating signal voltage}}$$

for example, '25 percent/volt at 1 kHz'.

9.10.2.4 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Voltage of supply,
b) Load details,
c) Modulating, and
d) Amplitude of modulating signal.

NOTE — This method may be used to determine the immunity of an oscillator to power supply line ripple, etc, by superimposing the modulating signal on the dc supply voltage.

9.10.3 *Amplitude Modulation Distortion (Non-linearity)*

9.10.3.1 *Purpose* — To measure the distortion resulting from the amplitude modulation process caused by non-linearity of the modulation transfer characteristic.

9.10.3.2 *Circuit* — The circuit diagram is given in Fig. 20A.

9.10.3.3 *Procedure* — A sinusoidal signal at the specified frequency, and at a level such as to modulate the oscillator to the specified index (*see* **9.10.1**) is applied to the external modulation terminal of the oscillator, and the spectrum analyzer adjusted to present a display of the frequency spectrum in the region of the output frequency of the oscillator, as in Fig. 20B.

where

f_o is oscillator output frequency.

f_m is frequency of modulating signal.

$f_o - f_m$ is lower sideband caused by the modulation signal.

$f_o - 2f_m$ is lower sideband caused by the second harmonic of the modulation signal.

$f_o - 3f_m$ is lower sideband caused by the third harmonic of the modulation signal, etc. The second, third, etc, harmonic distortion is usually expressed as d_2, d_3, etc, dB, but may also be expressed as

$$\frac{100}{\log_{10}^{-1}\left(\frac{d}{20}\right)}$$ percent distortion for each individual harmonic.

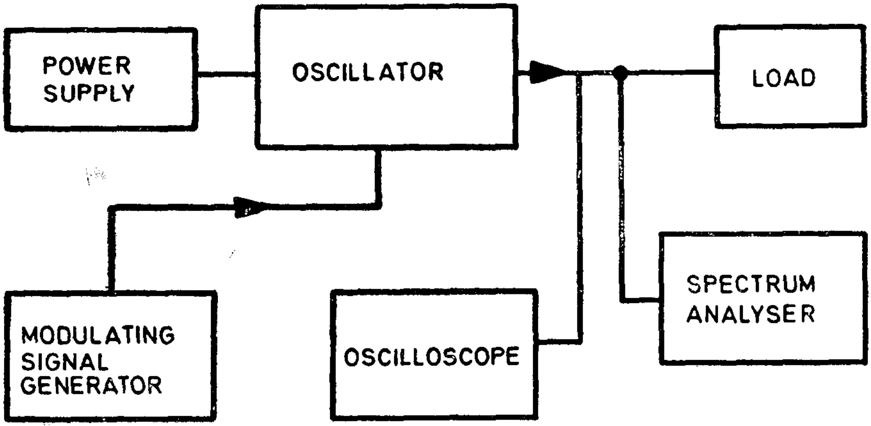
9.10.3.4 *Precautions* — Care shall be taken to prevent overloading of the spectrum analyzer, causing an apparent increase in modulation distortion.

The modulating signal shall be sinusoidal.

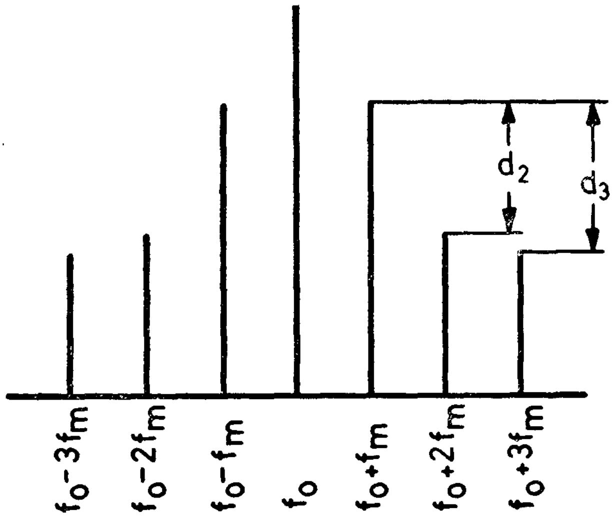
A spectrum analyzer i.f. bandwidth sufficiently low to provide adequate discrimination between the oscillator output and its sideband signals shall be used.

9.10.3.5 *Specified conditions*

a) Voltage of supply,
b) Load details,
c) Modulation input frequency, and
d) Amplitude modulation index for test.



20A



20B

Fig. 20 Measurement of Amplitude Modulation Distortion

9.10.4 *Amplitude Modulation Frequency Response*

9.10.4.1 *Purpose* — to measure the change in amplitude modulation sensitivity resulting from changes of the frequency of the modulating signal.

9.10.4.2 *Procedure* — The amplitude modulation sensitivity at a specified reference frequency is measured as in **9.10.2**, and the change in modulation sensitivity, usually expressed in decibels, between this and the modulation sensitivity, at other specified frequencies is measured.

9.10.4.3 *Precautions* — The modulating signal shall be sinusoidal.

9.10.4.4 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Supply voltage,
b) Load details,
c) Reference (modulation) frequency,
d) Modulation input level, and
e) Range of modulation frequencies for test.

9.10.5 *Pulse Amplitude Modulation*

9.10.5.1 *Purpose* — To measure the rise, fall, turn-on and turn-off times of the output waveform of an amplitude modulated oscillator when a specified pulse modulation signal is applied.

9.10.5.2 *Test circuit* — The circuit diagram is given in Fig. 21A.

9.10.5.3 *Procedure* — A pulse generator providing a modulation signal of specified waveform and repetition frequency shall be connected to the modulation input terminal of the oscillator. Both this signal and the output waveform of the oscillator are displayed simultaneously on the oscilloscope, with the peak-to-peak amplitude of the output waveform adjusted to be twice of the modulating signal as shown in Fig. 21B. The following parameters expressed in units of time may be determined from the superimposed oscilloscope display:

t_1 = *Turn-On Time*, the time interval between the 50 percent value of the modulating signal and the percent value of the output waveform, at the leading edge.

t_2 = *Rise Time*, the time interval between the 10 percent and 90 percent value of the leading edge of the output waveform (assuming that the modulation signal rise time is negligible).

t_3 = *Turn-Off-Time*, the time interval between the 50 percent value of the modulation signal and the 50 percent value of the output waveform, at the trailing edge.

t_4 = *Decay Time*, the time interval between the 90 percent and 10 percent values of the trailing edge of the output waveform (assuming that the modulation signal rise time is negligible).

9.10.5.4 *Precautions* — The repetition rate of the modulation signal should not be harmonically related to the oscillator frequency.

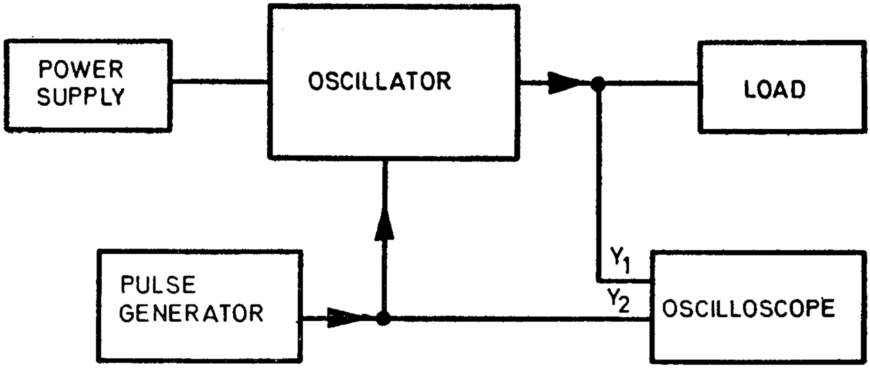
9.10.5.5 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Supply voltages;

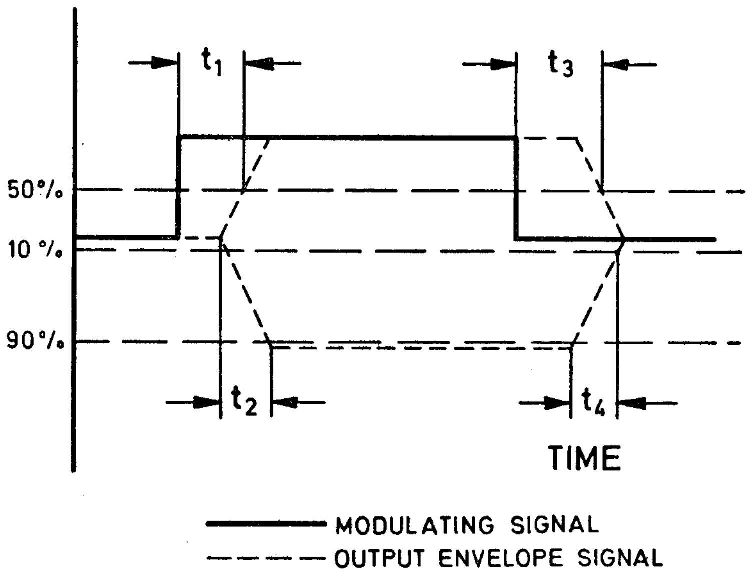
b) Load details;

c) Modulation signal repetition rate; and

d) Modulation signal waveform (rise and decay times, amplitude, and duration).



21A



21B

FIG. 21 MEASUREMENT OF PULSE AMPLITUDE MODULATION

9.10.6 *Amplitude Modulation Input Impedance*

9.10.6.1 *Purpose* — To measure the input impedance at the external modulation terminal of the oscillator when operating under specified conditions.

9.10.6.2 *Circuit* — The circuit diagram is given in Fig. 22.

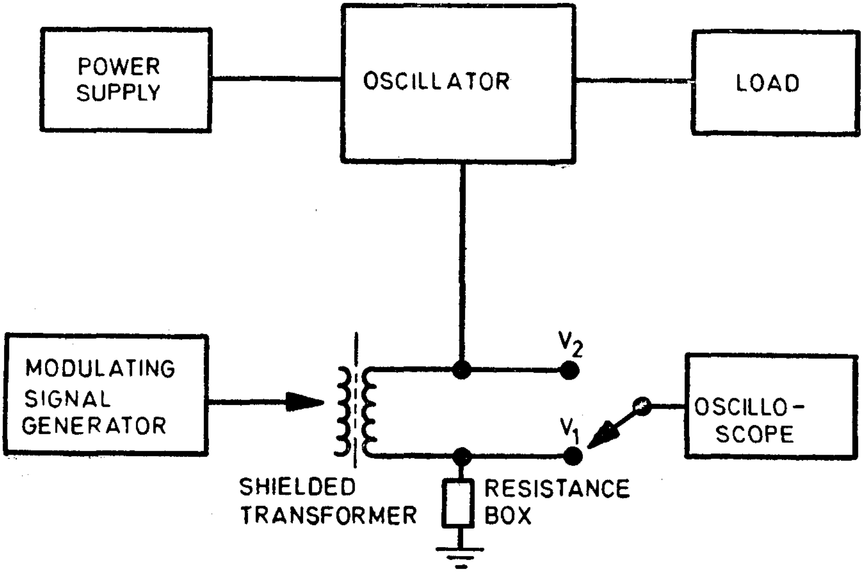


FIG. 22 MEASUREMENT OF AMPLITUDE MODULATION INPUT IMPEDANCE

9.10.6.3 *Procedure* — A signal generator providing a modulating signal at the specified frequency shall be connected to the external modulation terminal of the oscillator and to a resistance box through a shielded transformer, as shown in Fig. 22.

An oscilloscope (or suitable ac voltmeter) shall be connected so as to measure either the signal level across the resistance box (V_1) or the input level of the modulating signal to the oscillator (V_2).

The signal generator shall be adjusted such that the voltage level of the modulation signal at the input to the oscillator is at the specified level.

The modulation input impedance may then be calculated as:

$$Z = \frac{V_2}{V_1} R$$

NOTE — By this method, the magnitude of Z is determined directly, whether Z is a pure resistance or a complex impedance.

9.10.6.4 *Precautions* — The impedance of the resistance box shall be non-reactive at the specified measurement frequency.

9.10.6.5 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Voltage(s) of supply,

b) Load details,

c) Modulating signal frequency, and

d) Modulation input level.

9.10.7 *Incidental f.m. on an a.m. Signal*

9.10.7.1 *Purpose* — to measure the magnitude of the deviation of the incidental frequency modulation of an amplitude modulated signal.

9.10.7.2 *Procedure* — The amplitude modulation is adjusted to the specified index as in **9.10.1.** The resultant frequency modulation deviation is then measured as in **9.11.1.**

9.10.7.3 *Precautions* — The limiting action of the frequency multiplier(s) will remove most of the amplitude modulation from the signal. However, care shall be taken to ensure that the residual a.m. is insufficient to affect the accuracy of the frequency modulation meter.

9.10.7.4 *Specified conditions*

a) Frequency of modulating signal, and

b) Modulation index.

9.11 Frequency Modulation Characteristics

9.11.1 *Frequency Modulation Deviation*

9.11.1.1 *Purpose* — to measure the peak frequency deviation of a frequency modulated signal source (oscillator).

a) *Peak deviation greater than 100 Hz*

Circuit — The circuit diagram is given in Fig. 23A.

Procedure — The apparatus shall be connected as shown, and the peak deviation of the output signal measured using the f.m. modulation meter.

Precautions — When measuring very high frequency signals having a low peak frequency deviation, it may be necessary to use a local oscillator which is phase locked to a source having a low incidental f.m. content (for example, a crystal oscillator) in order to reduce its f.m. noise deviation.

Specified conditions

1) Supply voltage, and
2) Load details.

NOTE — Frequency modulation index $\beta = \frac{\delta f}{f_m}$

where

δf = actual peak frequency deviation, and

f_m = frequency modulating signal.

b) *Peak deviation less than 100 Hz*

Circuit — The circuit diagram is given in Fig. 23B.

Procedure — The peak frequency deviation of the signal shall be increased by frequency multiplication (*see* Note 2) to enable it to be measured the f.m. modulation meter.

$$\text{Actual peak deviation} = \frac{\text{measured peak deviation}}{\text{multiplication factor}}$$

Precautions

1) When measuring very high frequency signals having a low peak frequency deviation, it may be necessary to use a local oscillator which is phase locked to a source having a low incidental f.m. content (for example, a crystal oscillator) in order to reduce its f.m. noise deviation.
2) Most oscillators are in some measure susceptible to ripple on the supply; great care should be taken when measuring signals having a small frequency modulation index to ensure that supply voltage variations do not affect the measurement of peak frequency deviation.

Specified conditions

1) Supply voltage, and
2) Load details.

NOTE 1 — Frequency modulation index $\beta = \frac{\delta f}{f_m}$

where

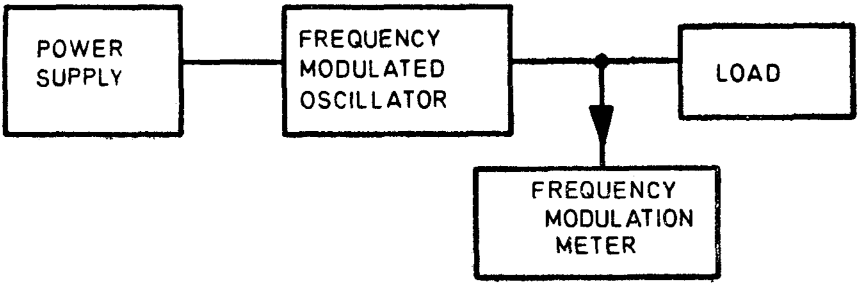
δf = actual peak frequency deviation, and

f_m = frequency modulating signal.

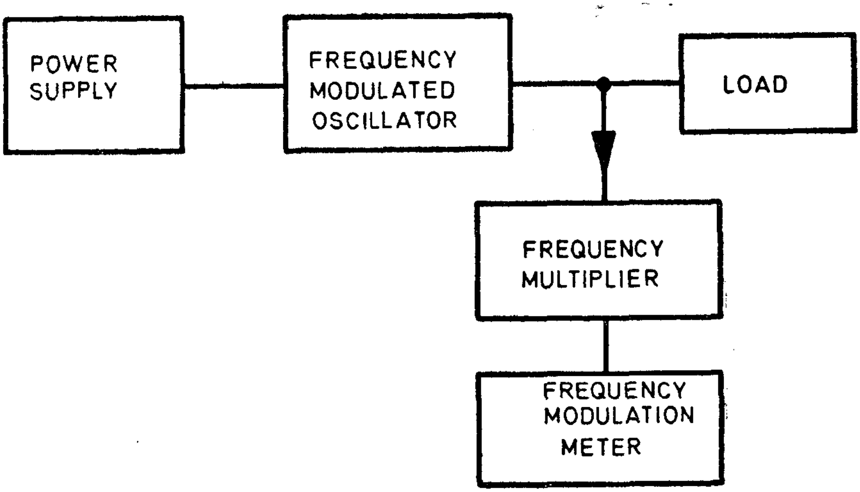
NOTE 2 — It may be necessary to use a mixer, before and/or after frequency multiplication, to down-convert the signal to bring it within the range of the modulation meter.

9.11.2 *Frequency Modulation Sensitivity*

9.11.2.1 *Purpose* — To measure the peak frequency deviation of a frequency modulated signal resulting from the application of a specified signal to the external modulation terminal of the oscillator.



23A



23B

FIG. 23 MEASUREMENT OF FREQUENCY MODULATION DEVIATION

9.11.2.2 *Circuit* — The circuit diagram is given in Fig. 24.

9.11.2.3 *Procedure* — A signal generator providing a modulating signal at the specified frequency shall be connected to the external modulation termination of the oscillator, and its output set to the specified amplitude as measured by the oscilloscope or valve voltmeter. The peak frequency deviation of the output signal shall be measured as described in **9.11.1**.

Generally, frequency modulation sensitivity is defined as the ratio

$$\frac{\text{Peak frequency deviation } \delta f}{\text{Peak-to-peak modulating signal voltage}}$$

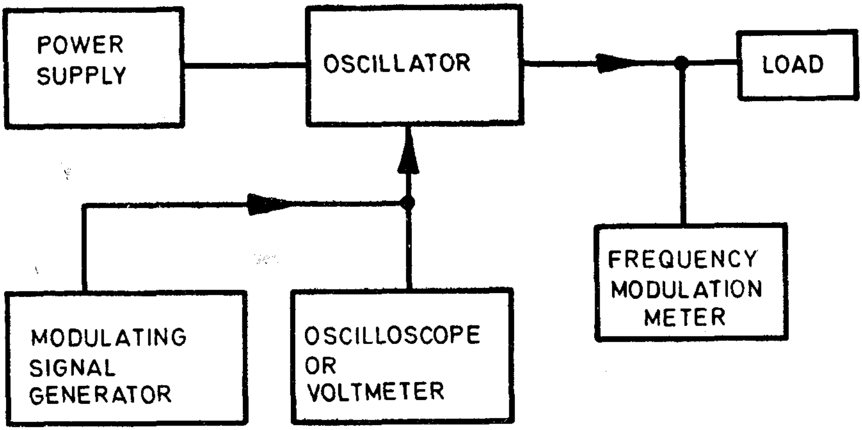


FIG. 24 MEASUREMENT OF FREQUENCY MODULATION SENSITIVITY

9.11.2.4 *Specified conditions* — The values of the following test conditions shall be stated in the detail specification:

a) Voltage of supply,

b) Load details,

c) Setting of any frequency adjustment provided,

d) Modulating signal frequency, and

e) Modulation input level (this must be such that the specified maximum permissible peak frequency deviation of the oscillator is not exceeded).

NOTE — This method may be used to determine the immunity of an oscillator to power supply line ripple, etc, by superimposing the modulating signal on the dc supply voltage.

9.11.3 *Frequency Modulation Distortion (Non-linearity)*

9.11.3.1 *Purpose* — To measure the distortion resulting from the frequency modulation process caused by non-linearity of the modulation transfer characteristic.

a) *Static test*

Circuit — The circuit diagram is given in Fig. 25A.

Procedure — A variable voltage dc power supply shall be connected to the external modulation terminal of the oscillator, and measurements of oscillator output frequency at various dc modulation control voltages as specified made. A graph of output frequency against control voltage shall be plotted and hence the modulation deviation linearity determined.

Specified conditions

1) Voltage of supply,
2) Load details,
3) dc control voltage range,
4) Setting of any frequency adjustment provided, and
5) dc control voltage increments.

b) *Dynamic test*

Circuit — The circuit diagram is given in Fig. 25B

Procedure — A sinusoidal signal at the specified frequency, and at a level such as to produce the specified modulation frequency deviation (*see* **9.11.1**) shall be applied to the external modulation terminal of the oscillator and the distortion of the output signal from the modulation detector (in the modulation meter) shall be measured with a distortion factor meter.

Precautions

1) The modulating signal shall be sinusoidal, and
2) Any distortion introduced by the detector of the modulation meter must be low compared with that of the oscillator under test.

Specified conditions

1) Voltage of supply,
2) Load details,
3) Modulating signal frequency,
4) Modulation frequency deviation, and
5) Setting of any frequency adjustment provided.

9.11.4 *Frequency Modulation Frequency Response*

9.11.4.1 *Purpose* — to measure the change in frequency modulation sensitivity resulting from changes of the frequency of the modulating signal.

9.11.4.2 *Procedure* — The frequency modulation sensitivity at a specified reference frequency is measured as in **9.11.2** and the change in modulation sensitivity, usually expressed in decibels, between this and the modulation sensitivity at other specified frequencies is measured.

9.11.4.3 *Precautions* — The modulating signal shall be sinusoidal.

9.11.4.4 *Specified conditions* — Values of the following test conditions shall be stated in the detail specification:

a) Supply voltage,

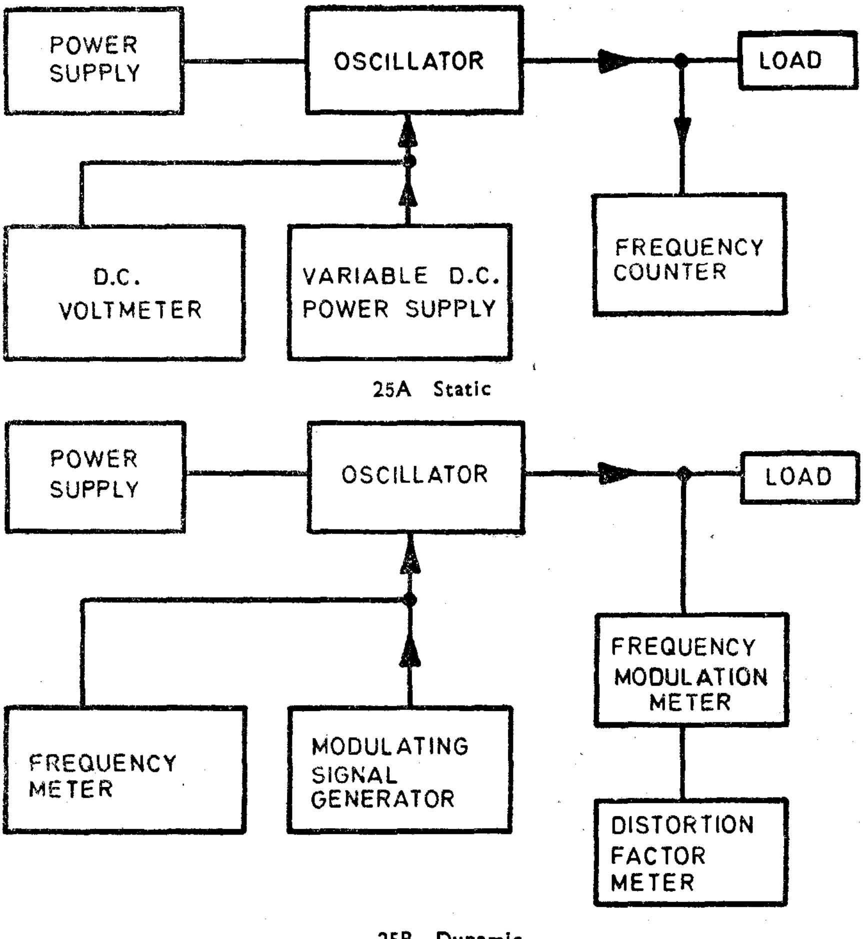


FIG. 25 MEASUREMENT OF FREQUENCY MODULATION DISTORTION

b) Load details,
c) Setting of any frequency adjustment provided,
d) Reference (modulation) frequency,
e) Modulation input level, and
f) Range of modulation frequencies (for test).

9.11.5 *Frequency Modulation Input Impedance* — This test is as described in **9.10.6**.

9.11.6 *Harmonic Distortion*

9.11.6.1 *Purpose* — to measure the harmonically related response of an oscillator.

9.11.6.2 *Circuit* — The circuit diagram is given in Fig. 26A.

9.11.6.3 *Procedure* — The circuit is set up as shown in Fig. 26A. The spectrum analyzer is set to display a frequency coverage which will embrace the appropriate harmonics of the oscillator.

In an ideal case the spectrum of the oscillator will appear as Fig. 26B, but Fig. 26C illustrates the spectrum of an oscillator with severe harmonic distortion. The spectra may be measured (usually directly in dB from the spectrum analyzer) as a power ratio with respect to the carrier power, expressed in dB; or alternatively the percentage distortion of, for example, the third harmonic may be quoted as follows:

$$D_3 = 100 \log_{10}^{-1} (- d_3/20)$$

where

D_3 = percentage of third harmonic distortion,

d_3 = difference in level of fundamental and third harmonic spectra (in dB) as measured on the spectrum analyzer.

9.11.6.4 *Precautions* — Care shall be taken to ensure that the distortion is not produced in the input mixer of the spectrum analyzer. Non-linear distortion (having the appearance of harmonic distortion) will be produced if the input mixer is over-loaded — this point may be checked by placing an attenuator between the oscillator and the spectrum analyzer and taking measurements at various power levels. The attenuators setting should not affect the percentage of harmonic distortion.

9.11.6.5 *Specified conditions* — The values of the following test conditions shall be specified in the detail specification:

a) Voltage of supply, and

b) Load details.

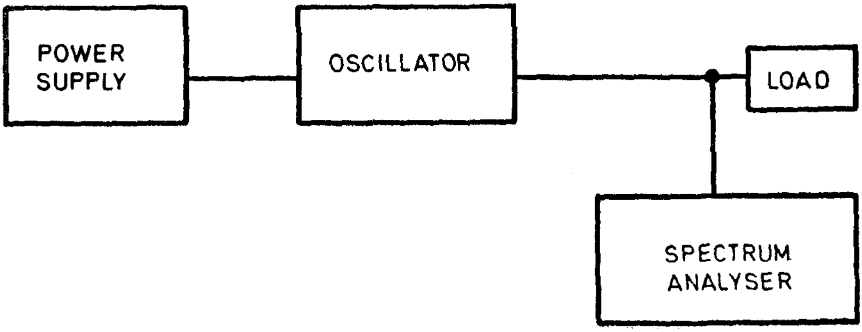
NOTE — The total harmonic distortion may be obtained from a summation of the individual harmonically related responses.

$$D_{TOTAL} = \frac{100}{\sqrt{\log_{10}^{-1} \frac{d_2^{2}}{20} + \log_{10}^{-1} \frac{d_3^{2}}{20} + \ldots\ldots\ldots\ldots}}$$

9.12 Spectral Purity Characteristics

9.12.1 *Spurious Responses*

9.12.1.1 *Purpose* — To measure the non-harmonically related or spurious response(s) of an oscillator. Note that sub-harmonics of the carrier are classed as spurious responses.



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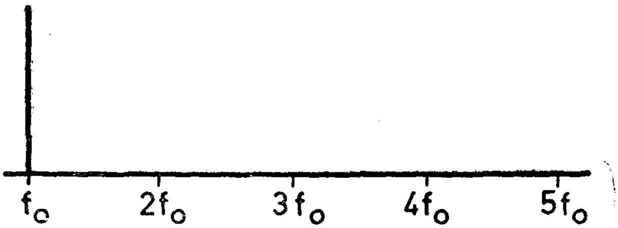
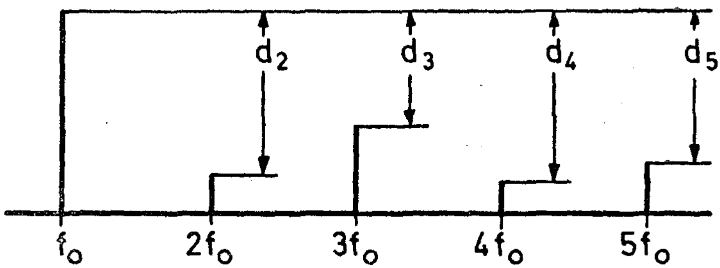


26B



26C

FIG. 26 MEASUREMENT OF HARMONIC DISTORTION

9.12.1.2 *Procedure* — The measurement circuit specified conditions etc are exactly as for **9.11.6** (harmonic distortion) except that the spurious oscillations will not be harmonically related to the fundamental frequency.

It is usual to quote a specification for spurious response(s) in decibels that is all spurious responses will be at least × dB below the main response.

9.12.1.3 *Precautions* — Should there by any high level signals in the environment in which the oscillator is being tested, care should be taken to

screen the measurement system. Spurious response(s) are, by definition, not harmonically related and so it is difficult to differentiate between oscillator generated spurious signals and those which may be picked up from the operating environment. This may be checked by removing supply voltage from the oscillator.

9.13 Short Term Frequency Stability (*see also* Appendix A)

9.13.1 *Frequency Domain Measurements*

a) *Phase noise*

Purpose — To measure the phase noise or phase jitter of an oscillator. The phase noise gives a measure of the short term stability of an oscillator in the frequency domain.

Circuit — The circuit diagram is given in Fig. 27A.

Description — Phase noise gives rise to a sideband distribution that consists of symmetrical pairs whose relative amplitude, compared to the carrier, is equal to 1/2 the peak phase deviation of that component in radians.

For the measurement of phase noise, synchronous signals are compared by means of a phase detector. The output of the phase detector is the instantaneous voltage analog of the phase noise contribution. For the phase detector to be held to zero output, except for the phase noise contributions, the oscillator under test (oscillator 2 in Fig. 27A) must be kept in quadrature with reference oscillator. This is achieved by using a dc amplifier to sense a zero phase detector output and hence drive the test oscillator to phase quadrature.

The output phase noise is monitored with a low frequency wave analyzer. The noise measured by the wave analyzer will be the rms noise (it may be necessary to perform a conversion for average/rms) in both sidebands; this may be converted to a single-sideband phase noise by subtracting 6 dB.

Ideally the reference oscillator (oscillator 1 in Fig. 27A) will have a very low noise contribution (that is a Caesium Beam Standard or similar). It frequently occurs that both oscillators are of similar type; if this is so, it may be assumed that both oscillators have equal noise contributions that is the signal-to-phase noise ratio will be degraded by 3 dB for similar oscillators. An appropriate allowance should be made when calculating the results.

Procedure — The circuit should be set up as in Fig. 27A. The feedback loop from the phase detector should be arranged such that oscillator 1 and oscillator 2 may be phase-locked in phase quadrature. The wave analyzer should be set to the specified resolution bandwidth (frequently 1 Hz) and the integrator time constant to 1 second, unless otherwise stated.

Calibration — Switch 1 is opened and a difference frequently is established between oscillator 1 and oscillator 2. The wave analyzer is adjusted

to the difference frequency and the scale on the X-Y recorder is calibrated by means of the attenuator in the region -60 to -80 dB (high attenuation to prevent over-loading of the low noise amplifier).

Measurement — Switch 1 is closed. Oscillators 1 and 2 are phase locked in quadrature. The attenuator is set to -10 dB, say, and the wave analyzer is tracked in frequency over the range of offset frequencies over which a plot of phase noise is required.

Precautions — The response time of the frequency-control loop must be very long compared to the period of the lowest side-band noise to be measured. For example, a 10-second response time (or, 0·1 Hz cut-off frequency) would be indicated in order to measure phase noise sidebands at 1 Hz. Within the pass-band of the locking loop, the output signal is proportional to frequency noise; far outside the locking-loop pass-hand, the output signal is proportional to phase noise; but in the transition region, the situation is somewhat complicated.

General precautions pertaining to the use of narrow-band tuned detectors must be followed; in particular, the tuning rate must be slow compared to the detector bandwidth, and the post-detector integration time must be long compared to the detector bandwidth. For example with a 10 Hz detector pass-band, the tuning (or slew) rate should be not greater than 1 Hz/second, and an integration time of at least 1 second should be used.

NOTE 1 — The limit of resolution of this measurement system is determined by the minimum bandwidth of the wave analyzer frequency 1 Hz. In this case, spectral components closer than 1 Hz to the carrier or having a periodicity slower than 1 second may not be measured. A typical plot of phase noise from an oscillator is shown in Fig. 27B.

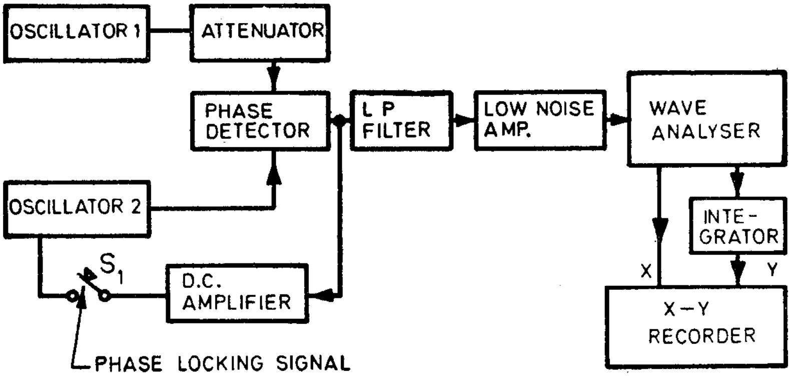
NOTE 2 — It is assumed that the noise contribution from the phase lock loop is small compared with the oscillator contribution. An alternative circuit arrangement is to manufacture the two oscillators with, say, a 25 kHz frequency separation and then to examine (with the wave analyzer) the noise distribution around the 25 kHz output from a mixer, which should be used in place of the phase detector — in this arrangement a band-pass filter (centered on the difference frequency) may be used instead of the low-pass filter. The disadvantage of this system is that it has an inherently lower stability and, in general, it will not be possible to use such low resolution bandwidths.

Specified conditions — The values of the following test conditions will be stated in the detail specification:

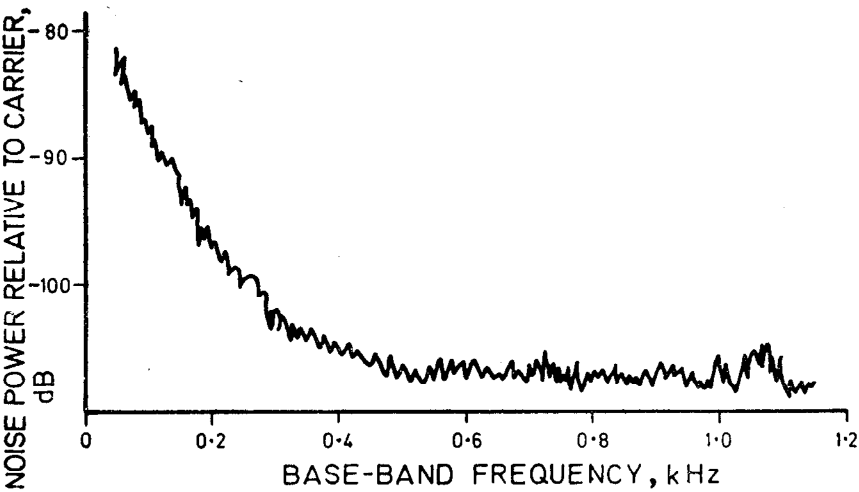
1) Voltage of supply,
2) Load details,
3) Frequency band over which single or double sideband phase noise shall be measured,
4) Resolution bandwidth of measuring system, and

NOTE — This should be increased from the 1 Hz frequently used if wide frequency coverage is required.

5) Integration time for recorder.



27A



27B

FIG. 27 FREQUENCY DOMAIN MEASUREMENTS

b) *Noise pedestal*

Purpose — To measure the noise pedestal, or far out-of-band noise level of an oscillator.

Circuit — The circuit diagram is given in Fig. 26A.

Description — The noise pedestal refers to the relative level of the carrier output of an oscillator to the level of noise at frequencies far removed from the carrier, excluding discrete harmonic tones or spurious single-frequency tones. The measurement of phase-noise in the enhancement

region near (within several bandwidths) the principal output frequency is given in **9.13.1** (a), while this refers to the 'flat' additive noise region extending from several kilohertz to as much several megahertz away from the principal output signal.

Procedure — The oscillator shall be connected as shown in Fig. 26A and the spectrum analyzer adjusted to display the desired frequency range. The level of the noise pedestal may be determined directly from the spectrum analyzer display (in dB), with appropriate correction for the analyzer bandwidth, that is, 10 dB per decade bandwidth in order to reduce the data to a one-Hz basis.

Precautions

1) Care shall be taken to ensure that the noise contribution of the spectrum analyzer does not degrade the measurement. This may be checked by inserting a variable attenuator between the oscillator and the spectrum analyzer, and determining that both carrier and noise levels respond equally to attenuator setting; and
2) In many cases, the signal-to-wide-band noise ratio of crystal controlled oscillators will greatly exceed the dynamic range of available spectrum analyzers; in this case, it will be necessary to use a narrow band-elimination filter to attenuate the carrier some known amount (that is, 80 or 90 dB) to avoid saturation of the analyzer. Alternatively, some demodulation scheme may be used, such as the narrow-band phase-locked loop to effectively remove the carrier.

NOTE — Since the additive noise level from a crystal controlled oscillator may be comparable to the thermal noise generated by the load impedance itself, great care is indicated in the selection of any amplifier or signal processing equipment used in its measurement.

Specified conditions — The values of the following test conditions shall be stated in the detail specification:

1) Supply voltage,
2) Load details,
3) Resolution bandwidth of the spectrum analyzer, and
4) Frequency separation from the carrier if a specific range is relevant.

c) *Incidental frequency modulation*

Purpose — To measure the incidental frequency modulation of an oscillator output signal.

Circuit — The circuit diagram is given in Fig. 28.

Description — Incidental f.m. refers to the residual or unintentional, frequency deviation characteristic of the oscillator output signal, particularly

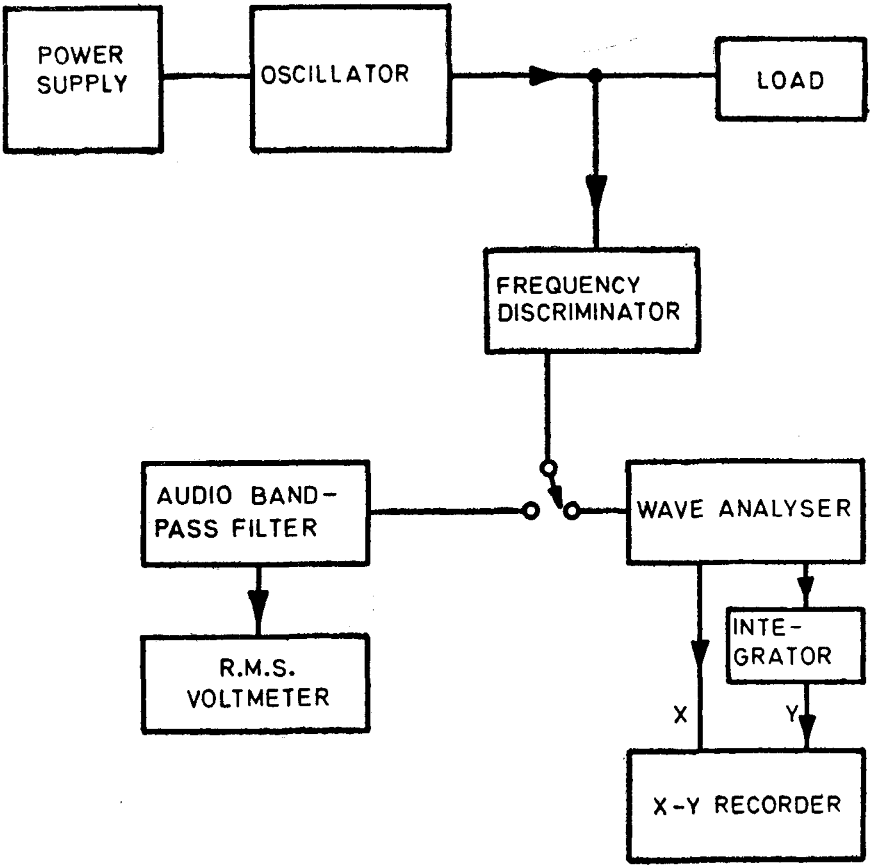


FIG. 28 MEASUREMENT OF INCIDENTAL FREQUENCY MODULATION

the frequency deviation components with base-band frequencies higher than about 10 Hz. This characteristic is usually of interest in the specification of signal sources used to generate carrier signals for communication purpose.

Procedure — The oscillator is connected as shown and allowed to stabilize. The frequency discriminator must provide a linear characteristic over a sufficiently wide band to prevent distortion of baseband spectural components in the range of interest. The incidental f.m. spectrum will be obtained directly on the X-Y recorder.

It is desired to determine the total f.m. signal in a particular base-band region, a suitable bandpass filter and rms voltmeter may be substituted

for the wave analyzer and X-Y recorder. In either case, it will be necessary to determine the discriminator characteristic (volts/Hz deviation) in order to establish the system calibration.

Precautions — The incidental f.m. of high quality crystal controlled oscillators is commonly very small, especially at low base-band frequencies requiring careful selection of low-noise discriminators and video amplifiers.

Post-detection integration time and wave-analyzer scanning rate must be adjusted to be compatible with the wave analyzer bandwidth in order to assure accurate measurement of discrete f.m. tones, such as those produced by power-supply ripple voltage, etc.

Specified conditions — Values of the following test conditions shall be stated in the detail specification:

1) Supply voltage,
2) Power supply ripple voltage,
3) Load details,
4) Baseband frequency range, and
5) Analyzer resolution bandwidth.

9.13.2 *Time Domain Measurements*

a) *RMS fractional frequency deviation*

Purpose — To measure the short term frequency stability of an oscillator in the time domain.

Circuit — The circuit diagram is given in Fig. 29A.

Description

1) The circuit should consist of 2 similar oscillators having a frequency separation of approximately 10 kHz or less. It will be assumed that the probability density and distribution functions of the oscillators are the same. The total measurable instabilities of the pair are equal to twice the instabilities of either oscillator. The variance measured is divided by two. Likewise the standard deviation is divided by $\sqrt{2}$.
2) Either a frequency counter with a direct interface to a computer, or a 'computing counter' may be used. The counters and their associated data recording devices must be capable of resolving the appropriate number of measurements in the specified time.

Procedure — The measurement system as shown in Fig. 29A is set up. The oscillators are chosen to be generally similar to each other that is manufactured in the same batch. It is assumed that the 10 kHz difference in the crystal frequencies does not change the statistics by a significant amount.

RMS fractional frequency deviations is defined in Appendix A, as the standard deviation of the data. The Allan deviation (square root of the Allan Variance) is a preferred measure of stability in the time domain:

$$\delta_y(\tau) = \delta_y(N, T, \tau) \simeq \delta_y(2, T, \tau) = E\left[\frac{1}{\sqrt{2}\,F_1}(F_{02} - F_{01})^2\right]^{\frac{1}{2}} \quad \ldots(1)$$

where

F_{01}, F_{02} = two successive samples of the beat frequency between similar oscillators, over an averaging time.

F_1 = long term average frequency of the oscillator under test.

$T \simeq \tau$ = the order of discrepancy is the recycle time of the counter and data transfer system which is assumed to be small compared to the averaging time.

Measurements of the beat frequency are taken for the specified averaging times and the rms fractional frequency deviation is calculated from equation (1).

The short term frequency stability may also be calculated from its relation as given in Appendix A.

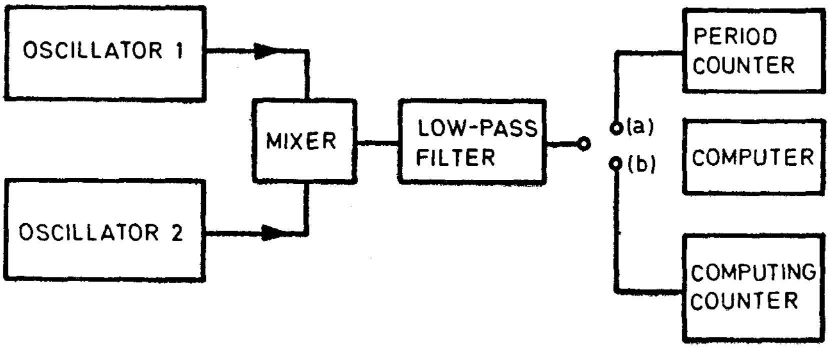
Precautions — The short term frequency stability of an oscillator is a very sensitive measure of the spectral purity and as such should be performed under controlled conditions. For high orders of stability, screened enclosures should be used, the digital recording apparatus being outside the enclosure.

An assumption has been made that the contribution of the two oscillators is similar. Should it not be possible to use two identical units, it is possible to use a crystal filter.

If a crystal filter is used as in Fig. 29B, the noise contribution of oscillator 1 may be minimized for measurement averaging times much shorter than the reciprocal of the bandwidth of the filter. For times longer than the reciprocal of the filter bandwidth, the filter should be removed from the system as it will degrade the measurable stability. In any case, the filter should be in stable temperature environment.

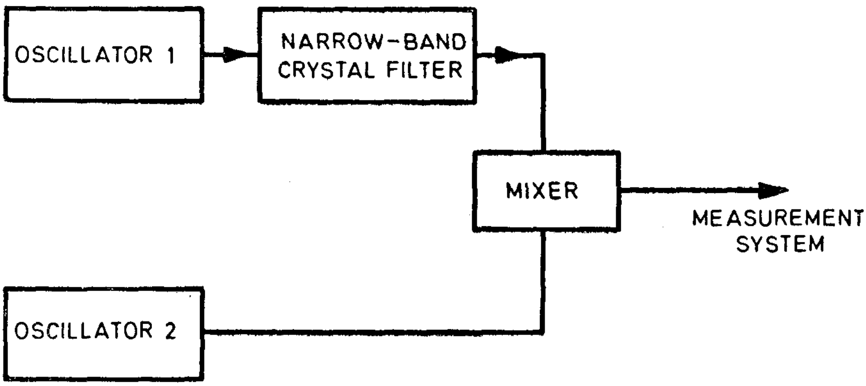
Specified conditions — The values of the following test conditions shall be stated in the detail specification:

1) Voltage(s) supply,
2) Ripple voltage of supply,
3) Oscillator load details,
4) Averaging time(s) for oscillator measurements and number of individual measurements for each averaging time, and
5) Details of oscillator operating environment.



29A

NOTE — Either (a) or (b) may be used to obtain the Allan deviation. (a) allows determination of standard deviation as well.



29B

FIG. 29 TIME DOMAIN MEASUREMENTS

Results — It is usual to characterize the short term frequency stability of an oscillator in graphical form as shown in Fig. 30. Such a characterization should be called for in the detail specification if required.

9.14 Electromagnetic Interference (Radiated)

9.14.1 *Purpose* — To determine the level of radiated electromagnetic interference emanating from a crystal oscillator.

9.14.2 *Test Arrangements* — The test arrangement is shown in Fig. 31A and 31B.

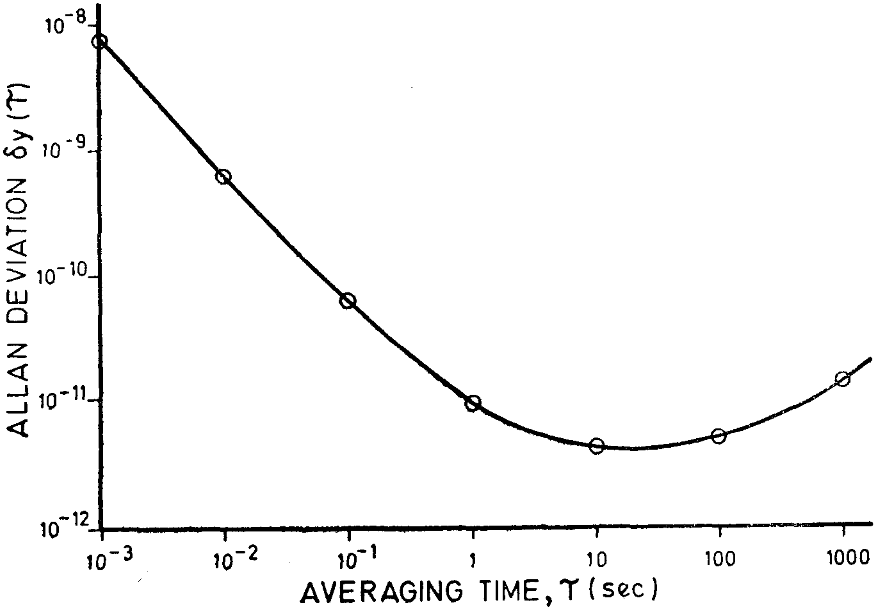


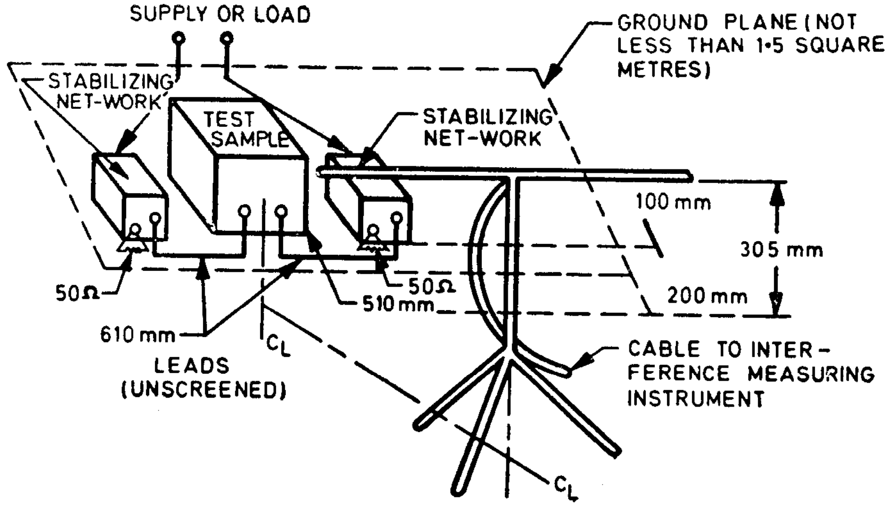
FIG. 30 SHORT TERM FREQUENCY STABILITY CHARACTERISTICS

9.14.3 *Test Conditions* — For tests of radiated interference it is essential that the test should be made in a screened room having dimensions not less than 2·4 m high, 2·1 m wide and 4·6 m long.

Ideally the tests for conducted interference should be made in a screened form having adequate filters in all incoming supply lines. If this is impracticable, precautions should be taken to ensure that the results are not affected by noise voltages and fields other than those due to the oscillator under test. This will involve the use of additional filters in the supply and/or load circuits.

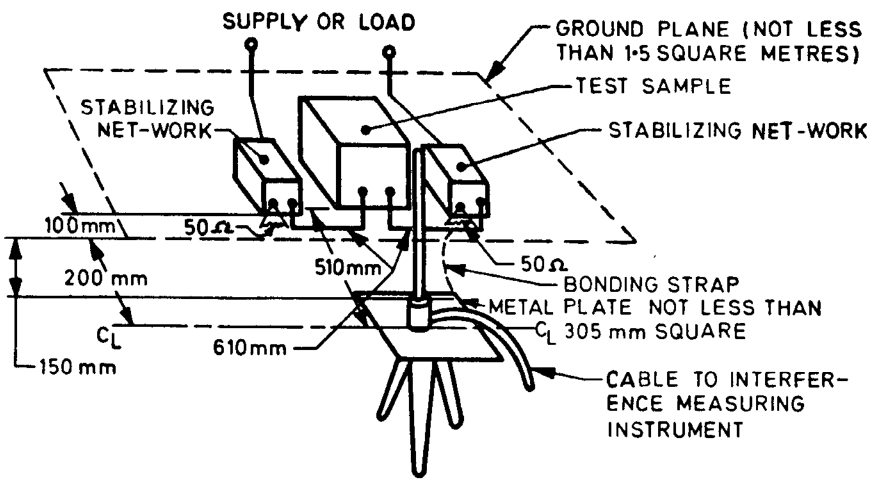
The test sample shall be mounted on the ground plane. The ground plane shall be bonded to the screened room at points not more than 0·9 m apart and at the ends of the ground plane.

The leads from the test sample to the line impedance stabilizing network shall be 610 mm in length and shall be screened or unscreened, as shown in the appropriate diagram. The stabilizing networks in the lines not being measured shall be terminated by 50 non-reactive resistors. The impedance characteristic of the stabilizing network shall be within the limits of Fig. 32. One practical method of attaining this impedance is shown in Fig. 33.



31A 30 MHz and Above

NOTE — Stabilizing network to be bonded to the ground plane.



31B Below 30 MHz

NOTE — Stabilizing network to be bonded to the ground plane.

FIG. 31 TYPICAL ARRANGEMENTS FOR RADIATED INTERFERENCE TESTS

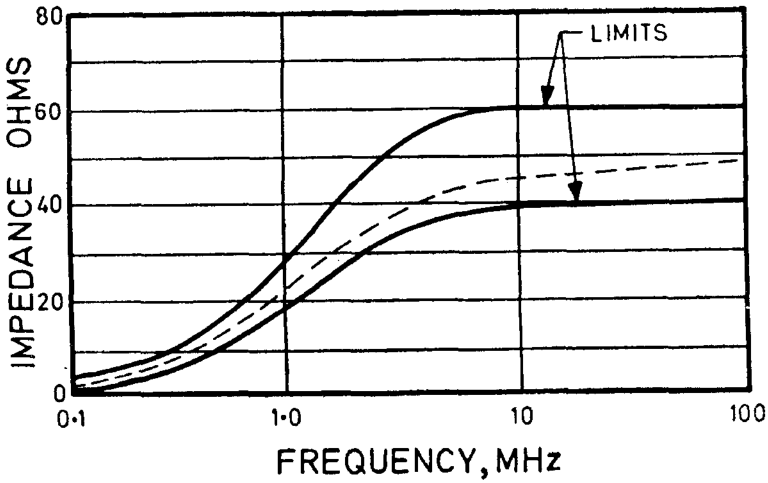
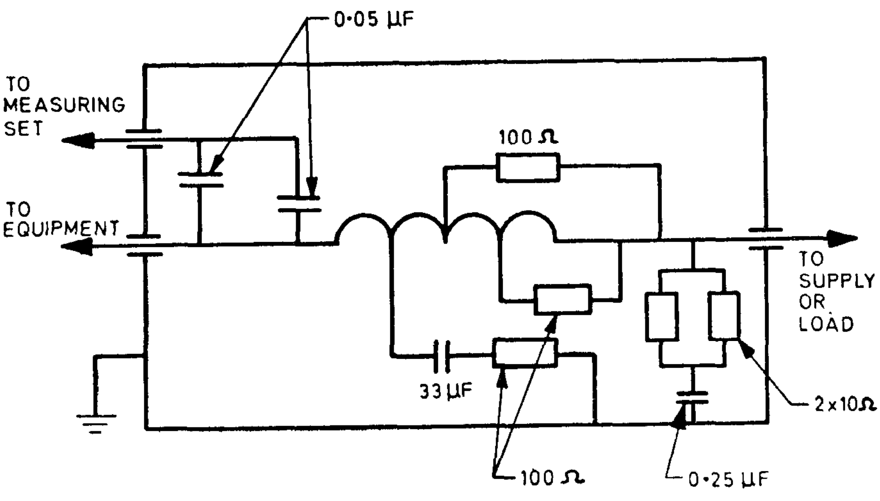


FIG. 32 IMPEDANCE CHARACTERISTICS OF STABILIZING NETWORK



Coil details: 5 μH, 10 Turns 6·0 mm (4 SWG) wound on 51·0 mm dia former

FIG. 33 CIRCUIT DIAGRAM OF LINE IMPEDANCE STABILIZING NETWORK

9.14.4 *Procedure* — The oscillator shall be set up in a screened room and with a measuring system as described above. The measurements shall be made under the load conditions producing the worst operating conditions from the point of view of radio interference.

A vertical rod aerial 1 016 ± 25 mm long shall be used at frequencies below 30 MHz. It shall be located at the point where maximum interference is obtained when it is moved along a line parallel with the front edge of the ground plane. At 30 MHz and above, a horizontal dipole aerial shall be used; over the frequency range 30 MHz to 50 MHz, a 50 MHz dipole shall be used and above 50 MHz a resonant dipole shall be used. It shall be placed with the front edge of the ground plane. Its height shall be 305 ± 25 mm above the level of the ground plane and its centre shall be adjacent to the geometrical centre of the unit under test. The rod or the dipole aerial shall be located 508 mm from the nearest point on the surface of the test sample. When the length of the dipole is less than that of the test layout, it shall be moved parallel to the edge of the ground plane to the point of maximum response.

9.14.5 *Measuring Sets* — Measuring sets having facilities for the measurement of peak values and having bandwidths within the limits shown below are preferred for measurements specified in this recommendation. Measuring sets having other bandwidths are acceptable provided suitable correlation factors are used:

Frequency Range	*Bandwidth Limits* (*at* − 6 *dB*)
0·05 MHz to 0·15 MHz	200 ± 100 Hz
0·15 MHz to 30 MHz	9 ± 1 kHz
30 MHz to 300 MHz	150 ± 50 kHz
300 MHz to 1 000 MHz	150 ± 50 kHz

All voltages measured shall be referred to 50Ω. If the input impedance of the measuring set differs from this value, a suitable matching network shall be used, and the appropriate correction factor applied.

When a measuring set has a quasi-peak voltmeter only, it will need to be modified to read peak voltages.

As the impulse bandwidth of measuring sets normally differs from 1 kHz an appropriate correction factor shall be applied on a linear basis.

In all cases, the measuring set shall be tuned for a maximum response to the interfering signal.

9.14.6 *Limits of Interference* — Three levels of interference are defined as follows:

Grade A — represents a very high degree of protection against the possibility of malfunctioning due to radiated or conducted interfering

voltages. It is compatible with internationally agreed requirements for equipment for military aircraft.

Grade B — represents a lesser degree of protection, compatible with RTCA Category A requirements which are normally imposed by the USA Federal Aviation Agency as a basis of certification of radio and electronic equipment intended for use in civil transport aircraft.

Grade C — represents a degree of protection considered adequate in aircraft which are not of a complex nature from the electrical/electronic/radio aspect and where a satisfactory installation can be achieved by careful disposition of equipment. It is compatible with RTCA Category B requirements.

Specified conditions — The values of the following test conditions shall be stated in the detail specification:

1) Voltage(s) of supply,
2) Load details,
3) Frequency range for interference measurement, and
4) Method of attachment (to ground plane).

10. ENVIRONMENTAL TESTS

10.0 Standard Conditions for Testing — Unless otherwise specified, all tests shall be carried out under standard atmospheric conditions as specified in IS : 589-1961*. When measurements are made at temperature other than the standard temperature, the results shall, where necessary, be corrected to the specified temperature. The ambient temperature during the measurements shall be stated in the test report.

10.1 Robustness of Terminations

10.1.1 *Tensile Test on Terminations* — The crystal oscillator shall be subjected to the tests in accordance with **7.19.1** of IS : 589-1961*. Unless otherwise stated in the detail specification, the loading weight shall be:

a) For pin terminations, 20 N compressive;
b) For pin terminations, 20 N tensile; and
c) For wire terminations, 10 N tensile.

10.1.2 *Bending Test on Wire Terminations* — The crystal oscillator shall be subjected to the test in accordance with **7.19.2** of IS : 589-1961*. Unless otherwise stated in the detail specification, the load shall be restricted so that the bond starts $2{\cdot}5 \pm 0{\cdot}5$ mm from the body of the oscillator. The loading weight shall be 5 N.

*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

10.2 Sealing Tests (for Hermetically Sealed Units)

10.2.1 *Sealing Test A* — The crystal oscillator shall be subjected to the test in accordance with Test A of **7.16** of IS : 589-1961*. During the test there shall be no evidence of leakage of gas or air from the inside of the oscillator unit. The continuous formation of bubbles shall be evidence of leakage. After one minute, the unit shall be removed from the chamber and exposed to the standard recovery conditions as specified in **4.4** of IS : 589-1961*.

10.2.2 *Sealing Test B* — The oscillator shall be subjected to the test in accordance with **7.21** of IS : 589-1961*. The maximum leak rate shall not exceed the value specified, unless otherwise stated in relevant specification.

10.3 Solderability — The oscillator shall be subjected to the solder bath (230 $\pm$ 10°C) test in accordance with **7.18.2** of IS : 589-1961*.

10.4 Rapid Changes of Temperature — The oscillators shall be subjected to the test in accordance with **7.14** of IS : 589-1961*. For non-temperature controlled oscillators, the low and high test chamber temperature shall be the extreme temperature of the low operating range stated in the detail specification. For temperature controlled oscillators, the low and high test temperature shall be -40 ± 3°C and $+100 \pm 3$°C, respectively. The oscillators shall be maintained for 30 minutes at each extreme of temperature. The oscillators shall be subjected to 10 complete thermal cycles and then exposed to standard atmospheric conditions for recovery for not less than 2 hours.

10.5 Bump — The oscillators shall be subjected to the bump test in accordance with **7.5.1** of IS : 589-1961* using a specified degree of severity, the oscillator being mounted or clamped. The three mutually perpendicular axes in which the bump is to be applied shall include:

a) an axis parallel to the termination, and

b) an axis parallel to the base of the oscillator unit.

10.6 Vibration

10.6.1 *Passive Vibration* — The oscillators shall be subjected to the vibration test in accordance with **7.6** of IS : 589-1961* using a specified degree of severity. The oscillators shall be mounted or clamped as required. The three mutually perpendicular axes in which the acceleration is to be applied shall include:

a) an axis parallel to the terminations, and

b) an axis parallel to the base of the oscillator unit.

10.6.2 *Active Vibration* — The oscillator shall be tested as in **9.6.1**, but during the test the oscillator shall be activated and electrical tests, as defined in the detail specification, shall be performed.

*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

10.7 Shock — The oscillators shall be subjected to the shock test in accordance with **7.5.2** of IS : 589-1961* using the specified severity. The oscillator shall be mounted or clamped as required. The three mutually perpendicular axes in which the shock is to be applied shall include:

a) an axis parallel to the terminations, and

b) an axis parallel to the base of the oscillator unit.

10.8 Acceleration, Steady State — The oscillators shall be subjected to the test in accordance with **7.7** of IS : 589-1961*. The oscillators shall be mounted or clamped as required. The procedure and severity shall be as stated in the detail specification.

10.9 Low Air Pressure — This test shall be subjected to the test in accordance with **7.12** of IS : 589-1961*.

10.10 Climatic Sequence

10.10.1 *Dry Heat* — The oscillators shall be subjected to the test in accordance with **7.2** of IS : 589-1961* at $100 \pm 3°C$ for 16 hours, unless otherwise stated in the detail specification.

10.10.2 *Damp Heat (Accelerated) First Cycle* — The oscillators shall be subjected to the test in accordance with **7.4** of IS : 589-1961* for one cycle of 24 hours. Unless otherwise stated in the detail specification, the unit shall be subjected immediately to the cold test.

10.10.3 *Cold* — The oscillators shall be subjected to the cold test in accordance with **7.1** of IS : 589-1961* at $-65 \pm 3°C$ for 2 hours, unless otherwise stated in the detail specification.

10.10.4 *Damp Heat (Accelerated) Remaining Cycles* — The oscillators shall be subjected to the test in accordance with **7.4** of IS : 589-1961* for remaining 5 cycles, each of 24 hours, unless otherwise stated in the detail specification.

10.11 Damp Heat (Long Term Exposure) — The oscillators shall be subjected to the test in accordance with **7.3** of IS : 589-1961* unless otherwise stated in the detail specification.

10.12 Salt Mist — The oscillators shall be subjected to the test in accordance with **7.10** of IS : 589-1961*. The test shall be carried out for 4 spraying periods of 2 hours, with a storage of 7 days after each, unless otherwise stated in the detail specification.

10.13 Mould Growth — The oscillators shall be subjected to the test in accordance with **7.9** of IS : 589-1961*.

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*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

10.14 Storage Temperature — The unenergized oscillator shall be placed in the test chamber and subjected to $-55 \pm 1°C$ for a period of 24 hours. At the end of this time the temperature of the test chamber shall be raised to $100 \pm 1°C$ and the oscillator shall be subjected to this temperature for 24 hours. After storage, the oscillator shall be tested at room temperature, and the output voltage of output frequency(ies) shall be within the specified tolerance.

11. ENDURANCE TEST

11.1 Ageing (Normal Conditions) — Oscillator units shall be maintained at 15 to 35°C for a period stated in the detail specification. The frequency shall be measured at appropriate intervals, at a temperature such that all measurements are taken within a total temperature excursion of $\pm 0.5°C$.

11.2 The output frequency shall be measured as in **9.4** (output frequency); the accuracy and resolution of the frequency measuring system shall be ± 5 pp 10^7 or ± 10 percent of the allowed ageing over the intervals between measurements, whichever is the smaller, oscillators shall be stored in an energized condition unless otherwise stated in detail specification.

APPENDIX A

(*Clause* 9.13)

GUIDANCE ON SHORT TERM FREQUENCY STABILITY

A-0. GENERAL

A-0.1 The output signal produced by a crystal oscillator consists of a complex spectrum, containing not only the desired single frequency component, but also includes additive thermal-noise voltages, harmonic distortion components and components reflecting various environmental effects. Consequently, the instantaneous frequency of the signal will not be a constant, but will be somewhat different from one instant to another. Short-term frequency stability is the general descriptive term used to indicate the extent of this deviation of instantaneous frequency from a constant value, and usually implies that deterministic effects (such as frequency ageing, voltage and temperature variations, etc) have been eliminated from consideration.

A-0.2 The user of a frequency generator will generally be interested in a useful measure of the characteristics of the output signal fluctuation so that he may accurately predict its effect on a particular system. The oscillator designer, however, will often be interested in relating particular device characteristics to the resultant frequency fluctuations. The objective of this appendix is to present useful measures of the frequency fluctuation

characteristic of a signal which are sufficient to allow predictions of performance of systems utilizing these signals and also to point out some relationships between the frequency fluctuation characteristic and particular kinds of corrupting influences.

A-1. MEASURES OF SHORT-TERM FREQUENCY STABILITY (FREQUENCY DOMAIN)

A-1.1 The conventional definition of instantaneous frequency is:

$$F(t) = \frac{1}{2\pi} \frac{d}{dt} [\phi(t)] \quad \text{...(A-1)}$$

the time derivative of the phase function. The output signal of an oscillator can be written as:

$$\begin{aligned} V(t) &= [V_0 + \Sigma(t)] \text{ Sin } \phi(t) \\ &= [V_0 + \Sigma(t)] \text{ Sin } [2\pi F_0 t + \varphi(t)] \quad \text{...(A-2)} \end{aligned}$$

where V_0 is the average (mean) amplitude, and F_0 is the average (mean) frequency. If the fluctuations from the mean are small, that is:

$$\left| \frac{\Sigma(t)}{V_0} \right| << 1 \quad \text{...(A-3)}$$

$$\left| \frac{\varphi(t)}{F_0} \right| << 1 \quad \text{...(A-4)}$$

then the phase fluctuation function (t) may be unambiguously defined and we may write the expression for instantaneous frequency:

$$F(t) = F_0 + \frac{1}{2\pi} \varphi(t) \quad \text{...(A-5)}$$

Hence, the fractional frequency fluctuation function is:

$$Y(t) = \frac{F(t) - F_0}{F_0} = \frac{1}{2\pi F_0} \varphi(t) \quad \text{...(A-6)}$$

Since this function is an essentially noise-like random function of time, it cannot be perfectly measured; as with any noise-like quantity useful estimates must be obtained from time-averaged measurements.

The preferred measure of fractional-frequency stability in the frequency domain is the power-spectral density of the fractional frequency fluctuations:

$$S_y(f),$$

where f is the Fourier frequency (sometimes referred to as the base-band frequency).

In some instances, it is useful to use the related function, the power spectral density of phase fluctuation [(t) in Eq A-2]:

$$S_\varphi(f)$$

The relationship between the two is just:

$$S_\varphi(f) = \frac{F_o^2}{f^2} S_y(f) \quad \ldots(A\text{-}7)$$

Since the two are mathematically related, either $S_y(f)$ or $S_\varphi(f)$ may be used to describe the frequency-fluctuation characteristic; however, $S_y(f)$ is the usually preferred measure.

Other frequency domain measures of frequency stability sometimes employed are the following:

A-1.1.1 *Incidental FM* — This term is used to describe the random frequency fluctuation of the oscillator output signal in terms of the amplitude of the frequency fluctuation function, either as a Fourier amplitude spectrum or as a total effective value for a specified system bandwidth.

As a function of the base-band frequency, the incidental f.m. amplitude spectrum can be expressed as:

$$\left(\frac{\Delta F}{F}\right)(f) = [S_y(f)]^{\frac{1}{2}}$$

with the dimensions of $Hz^{-1/2}$.

To determine the total effect on a finite-bandwidth system, for example, the rms signal output resulting from the application of the oscillator output to an ideal frequency discriminator having an effective base-band response from f_a to f_b. The uncorrelated random components on a power basis shall be summed up:

$$\left[\frac{\Delta F}{F}(f_a, f_b)_{rms}\right] = \left[\int_{f_a}^{f_b} S_y(f)\, df\right]^{\frac{1}{2}}$$

A-1.1.2 *Phase Noise (Jitter)* — This term refers to the phase fluctuation function $\varphi(t)$ in Eq A-2, in terms of its amplitude. It may be expressed as a Fourier amplitude function,

$$\Delta\phi(f) = [S_\varphi(f)]^{\frac{1}{2}}$$

having the dimensions of radians/$Hz^{1/2}$, or, as in the case of incidental f.m. it may be stated in terms of a total effective value for a specified bandwidth. For example, the total effective phase fluctuation produced in a system having a base-band response from f_a to f_b may be determined by combining the non-correlated spectral components in a power sense:

$$\Delta\phi(f_a, f_b)_{rms} = \left[\int_{f_a}^{f_b} S_\varphi(f)\, df\right]^{\frac{1}{2}}$$

A-2. MEASURES OF SHORT-TERM FREQUENCY STABILITY (TIME DOMAIN)

A-2.1 In many applications of crystal oscillators (as well as other precision frequency generators); the fluctuation of frequency from its average value

is of more use when expressed in terms of its time and time-average characteristics rather than in terms of its Fourier Frequency characteristics. For example, in timing applications, it is of fundamental importance to determine the deviation from a constant value of the interval determined by counting a prescribed number of zero-crossings of the oscillator signal.

The fundamental time domain definitions of short-term frequency stability is based on the sample variance of a number of sequential determinations of frequency, each averaged over a specified sampling interval. Let Y_k represent the kth determination, defined as

$$Y_k = \frac{1}{\tau} \int_{t_k}^{t_k + \tau} Y(t)\, dt = \frac{\varphi(t_k + \tau) - \varphi(t_k)}{2\pi F_o}$$

where τ is the specified sampling period, and

$$t_k + 1 = t_k + T,\ k = 0, 1, 2 \ldots\ldots\ldots$$

T is the repetition interval, $T \geqslant \tau$.

From a large number of samples, then the expectation value of the sample variance may be defined as

$$\delta^2_Y(N, T, \tau) = \frac{1}{N-1} - \sum_{k=1}^{N} (Y_k - Y_o)^2$$

where

$$Y_o = \frac{1}{N} \sum_{K=1}^{N} Y_k \quad \text{is the mean value of the samples.}$$

Unfortunately, it can be shown that this expression does not always converge to a meaningful limit as $N \rightarrow \propto$. Consequently, it is of utmost importance to specify both N and T as well as τ, if data is to be of use.

To avoid the convergence problem for large N, it is proposed that the preferred measure of frequency stability in the time domain is the Allan variance:

$$\delta^2_Y(\tau) = \delta^2_Y\ (2, \tau, \tau) = \frac{(Y_{k+1} - Y_k)^2}{2}$$

Experimental estimates of $\delta^2_Y(\tau)$ must be based on finite samples of data, and can never be measured with perfect confidence. In practice, one uses some specified number of data, and estimates the Allan variance as

$$\delta^2_Y(\tau) = \frac{1}{M-1} \sum_{k-1}^{M-1} \frac{(Y_{k+1} - Y_k)^2}{2}$$

Since it can be shown that the ensemble average of $\delta^2_Y\ (2, \tau, \tau)$ is convergent as $M \rightarrow \infty$ for noise processes that do not have convergent $\delta^2\ (N, \tau, \tau)$, $N \rightarrow \infty$, this is the preferred time-domain measure.

A-2.2 RMS Fractional-Frequency Fluctuation — The time-domain characteristics of fractional-frequency fluctuation are often stated in terms of the deviation rather than variance, and termed the root-mean-square value. In a statistical sense, the rms value is defined as the square root of the variance, and is equal to the deviation:

$$\delta_Y\ (N, T, \tau) = [\,\delta^2_Y\ (N, T, \tau)\,]^{1/2}$$

Because of the non-convergence of the usual statistical variance of frequency-fluctuation determinations discussed above, the preferred definition of rms frequency deviation is based on the Allan variance:

$$\frac{\Delta F}{F_0}(\tau)_{\text{rms}} = \delta^2_Y\ (\tau)^{\frac{1}{2}} = \left[\frac{1}{M-1}\sum_{k=1}^{M-1}\frac{(Y_{k+1}-Y_k)^2}{2}\right]^{\frac{1}{2}}$$

The sample averaging time, τ, as well as the total number of samples, M, must be specified.

The specification of this quantity for a single sample averaging time is obviously not sufficient to describe the behaviour of the frequency-fluctuation function. Usually, the value of $\frac{\Delta F}{F_0}(\tau)_{\text{rms}}$ is specified for a relatively wide range of τ so that the response of particular systems can be estimated. An example of the τ-depondence is shown in Fig. 34.

Experimentally, it is difficult to obtain consecutive measures of average frequency with zero dead-time between samples. However, at least in the case of most commonly encountered noise processes, it is possible to translate among different sets of N, T and τ values, by making use of two 'bias functions' which have been computed and tabulated. These functions, B_1 and B_2, are defined by the relations

$$B_1\ (N, r, \mu) = \frac{\delta^2_Y\ (N, \pi, \tau)}{\delta^2_Y\ (2, T, \tau)}$$

$$B_2\ (r, \mu) = \frac{\delta^2_Y\ (2, T, \tau)}{\delta^2_Y\ (2, \tau, \tau)}$$

where $r = T/\tau$, and $\mu = (\alpha + 1)$, α being obtained from the power-low expression for spectral density of frequency fluctuation.

$$S_Y\ (f) = \Sigma C\alpha \quad f^{\alpha}$$

Fortunately, most real world noise processes can be characterized by power-low spectra, so that technique can be very useful.

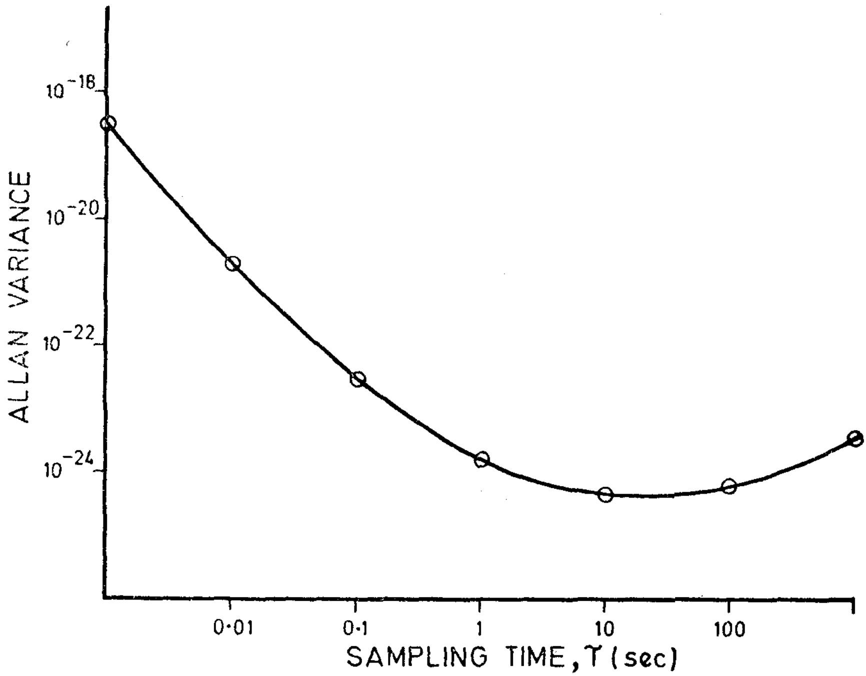

FIG. 34 TYPICAL DEPENDENCE OF ALLAN VARIANCE OF FREQUENCY DETERMINATIONS ON SAMPLING TIME

A-3. RF POWER SPECTRUM

A-3.1 The instantaneous output voltage of a crystal oscillator (Eq A-2) in general demonstrates both amplitude and frequency fluctuations as compared with the ideal signal. The presence of these fluctuations gives rise to a power spectrum which can very generally be described as an intense narrow line centered at the nominal frequency F_0, and a distribution of low-intensity random components extending over a broad frequency spectrum. The shape of the power spectral density of r.f. power will depend upon the detailed structure of the oscillator and amplifier circuits within the oscillator package, as well as upon the environmental situation in which the measurement is made. While this total power spectrum may be of primary importance in determining the performance of a particular system, it is not uniquely related to the frequency-fluctuation function. Only in certain cases, when sufficient detailed information about the nature of the perturbing signals in the spectrum is known, can their effects on instantaneous frequency be accurately assessed. Consequently, a specification of the r.f. power

spectrum does not constitute a specification of the short-term frequency stability.

As an example, a hypothetical situation in which the r.f. spectrum of an oscillator output signal consists of a single-frequency component of ideal characteristics superimposed on a low-level background of random, white noise, is as shown in Fig. 35. At any instant, the composite signal will consist of the vector sum of the ideal frequency component, $A_c \sin 2\pi F_0 t$, and the instantaneous vector sum of all the uncorrelated noise components, $a_n \sin [2\pi F_0 t + \phi(t)]$. If we let a_n represent the maximum magnitude which the vector sum of all the noise components can achieve, then the circle shown in Fig. 36 represents the range of possible termini of the composite signal vector with respect to the ideal component voltage, and $\Delta\phi$ is the maximum value of the phase deviation.

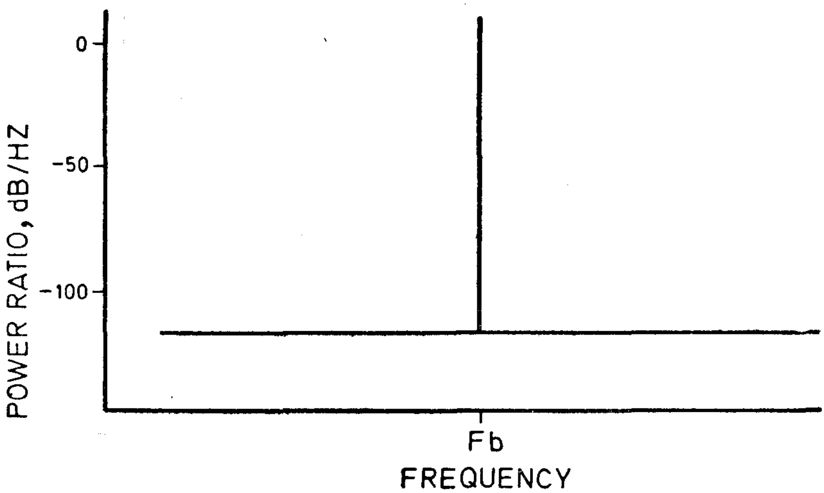

FIG. 35 R.F. POWER SPECTRUM OF IDEAL OSCILLATOR WITH WHITE NOISE

From Fig. 36 it is clear that the noise component may at any instant be resolved into two components, one co-linear with A_c, and one normal to it. If the value of a_n is small compared to A_c, then the phase deviation is seen to depend only on the normal component, while the amplitude deviation depends only on the colinear component. Since a_n is assumed to be a random component, then we may generalize by stating that, on the average, half the noise sideband power is contained in the normal, or quadrature components, and half is in the in-phase components.

Also, from Fig. 37, it is clear that essentially no change in the phase-deviation characteristic results from passing the signal through a hard limiter,

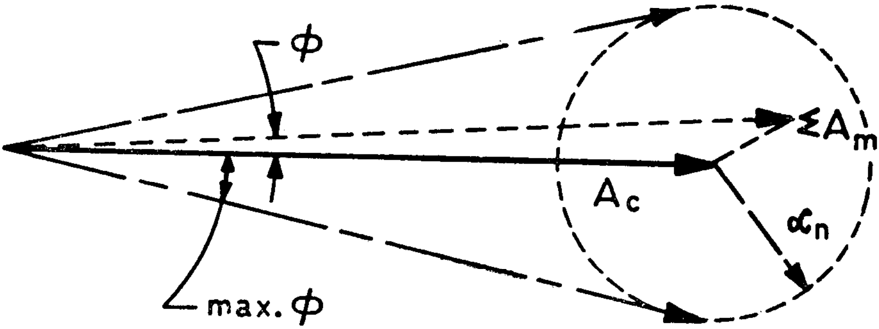

FIG. 36 VECTOR COMBINATION OF CARRIER AND UNCORRELATED NOISE

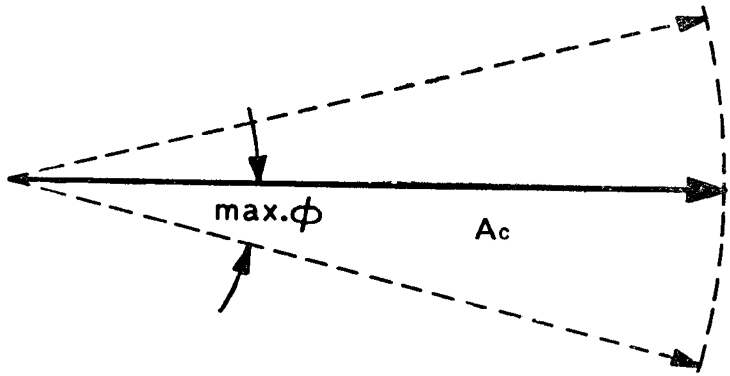

FIG. 37 EFFECTS OF REMOVING A.N. NOISE COMPONENTS

which removes the amplitude-deviation components, thus reducing the average noise sideband power by one-half. Consequently, we may conclude that measurement of the phase (or frequency) deviation characteristic does not give us unique information concerning the r.f. power spectrum, nor does the r.f. power spectrum itself uniquely define the phase (or frequency) deviation characteristic.

The r.f. power spectrum, expressed as a ratio of sideband power in a one-Hz band to total signal power, is sometimes called the spectral purity of the signal.